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International Waste Technologies/Geo-Con In situ Stabilization/Solidification: Applications Analysis Report

Foster Wheeler Enviresponse, Inc., Edison, NJ

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16. ABSTRACT

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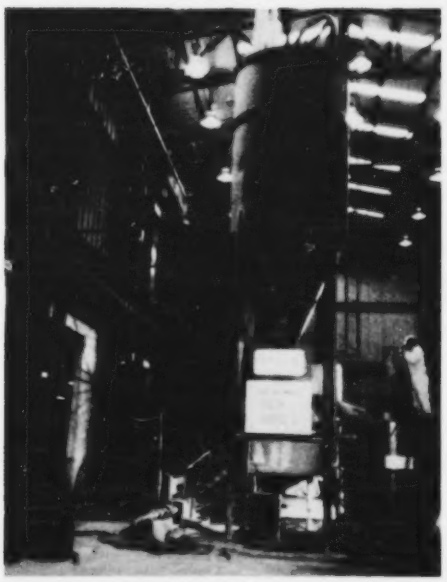

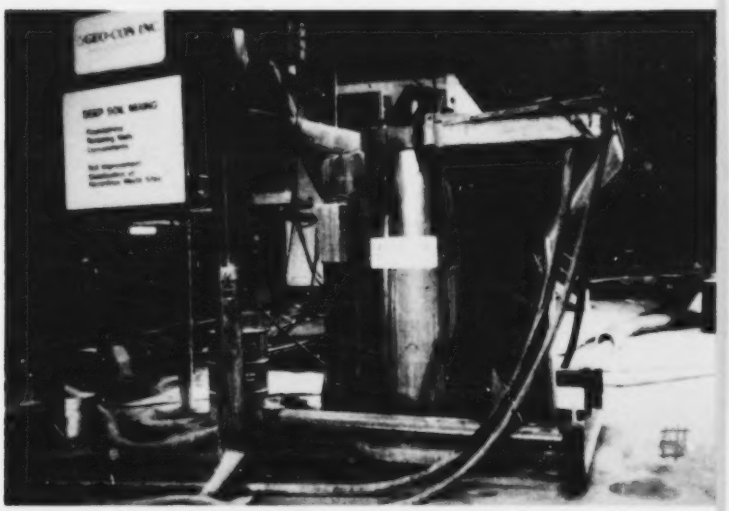

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August 1990

International Waste Technologies/ Geo-Con In Situ Stabilization/Solidification

Applications Analysis Report

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency under Contract No. 68-03-3255 and the Superfund Innovative Technology Evaluation (SITE) Program. It has been subjected to the Agency's peer review and administrative review and it has been approved for publication as a USEPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use

Foreword

The Superfund Innovative Technology Evaluation (SITE) program was authorized in the 1986 Superfund amendments. The program is a joint effort between EPA's Office of Research and Development and Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous-waste treatment technologies that will be necessary to meet new cleanup standards, which require greater reliance on permanent remedies. This is accomplished through technology demonstrations that are designed to provide engineering and cost data on selected technologies.

This project consists of an analysis of the International Waste Technologies/Geo-Con proprietary in situ stabilization/solidification process and represents the sixth field demonstration in the SITE program. The technology demonstration took place at a former electric service shop owned by General Electric Company in Hialeah, Fla. The demonstration effort was directed at obtaining information on the performance and cost of the process for use in assessments at other sites. Documentation will consist of two reports. The Demonstration Report describes the field activities and laboratory results and has been previously issued. This Applications Analysis Report provides an interpretation of the available data and presents conclusions on the results and potential applicability of the technology.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Bldg., Springfield, VA, 22161, 703-487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at 1-800-424-9346 or 202-382-3000 in Washington, D.C. to inquire about the availability of other reports.

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Abstract

An evaluation was performed of the International Waste Technologies (IWT) HWT-20 additive and the Geo-Con, Inc. deep-soil-mixing equipment for an in situ stabilization/solidification process and its applicability as an on-site treatment method for waste site cleanup. The analysis of this technology is contained in two reports, the Technology Evaluation which describes the demonstration and this Applications Analysis which evaluates the technology based upon all available data.

A demonstration was held at a General Electric Co. electric service shop in Hialeah, Florida, which provided the bulk of the information for the technology evaluation. Operational data and sampling and analysis information, for this first field application of the IWT additive, were carefully monitored and controlled to establish a database against which other available IWT and Geo-Con data, and their claims for their technologies, could be compared and evaluated. Conclusions were reached concerning the technology's suitability for use in cleanups of various contaminants and at different locations.

The technical criteria used to evaluate the effectiveness of the in situ process were contaminant mobility (based on leaching and permeability tests), and the potential long-term integrity of the solidified soils (based on some physical tests and microstructural studies). The Geo-Con deep-soil-mixing system was also evaluated.

Since the most controlled sampling on the IWT additive was performed during the demonstration, much of the emphasis of the evaluation is based upon this data. Test samples were taken of the site material before treatment to characterize the site and of the solidified materials after curing for 5 weeks. Samples of treated and untreated material were analyzed to determine: physical properties (such as unconfined compressive strength and permeability) that along with the microstructural studies provides clues to long-term durability of the treated mass; chemical properties (such as soil composition and leachability) that provide information on contaminant mobility.

This report evaluates the in situ process (based on the test results of the demonstration), other data provided by the technology developers, and the general capabilities of cement-based systems. It also discusses the probable applicability of the technology to sites other than the GE electric service shop.

Abstract (Continued)

The conclusions drawn from the available data are that: (1) immobilization of polychlorinated biphenyls (PCBs) appears likely, although due to low leachate concentrations for both the treated and untreated soils -- a result of the low concentrations of PCBs in the soil encountered in most of the tests -- it cannot be confirmed; (2) heavy metals can probably be immobilized; (3) volatile organics can bereduced to low concentrations in treated soil leachates, but the ability to immobilize is not clear; (4) a small volume increase on the order of magnitude of 5%-10% can be expected; (5) the solidified material shows satisfactory physical properties- - with high unconfined compressive strengths, moderately low permeabilities, and satisfactory integrity for the wet/dry samples -- but unsatisfactory integrity for the freeze/thaw samples; and (6) microstructural results show a dense, low-porosity, homogeneous mass -- indicating a potential for long-term durability.

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Abbreviations and Symbols

ANS 16.1	Modified American Nuclear Industry Leaching Test Methods
ARARS	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
BDAT	Best Demonstrated Available Technology
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
cm/s	centimeters per second — permeability units
DSC	differential scanning calorimetry
DSM	deep soil mixing
EPA	Environmental Protection Agency
EP Tox	Extraction Procedure Toxicity Test
°F	degrees Fahrenheit
FTIR	Fourier transform infrared
ft^3	cubic feet
FY	fiscal year
F006	wastewater treatment sludges from electroplating operations
F012	quenching wastewater-treatment sludges from metal heat-treating operations where cyanides are used
F019	wastewater treatment sludges from the chemical conversion coating of aluminum
g/ml	grams per milliliter
GC/ECD	Gas chromatography/electron capture detector
GC/MS	Gas chromatography/mass spectrometry
Geo-Con	Geo-Con, Inc.
GE	General Electric Company
gpm	gallons per minute

Abbreviations and Symbols (Continued)

HSWA	Hazardous and Solid Waste Amendments to RCRA - 1984
HWT-20	Treatment additive offered by IWT
IWT	International Waste Technologies
kW	Kilowatt(s)
kWh	Kilowatt hour
lb/min	pounds per minute
LDR	Land Disposal Restriction
LE	Law Environmental, Inc.
MCC-1P	Materials Characterization Center Static Leach Test Method
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
NCP	National Contingency Plan
NPL	National Priorities List
O&G	oil and grease
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
PCBs	polychlorinated biphenyls
PCP	pentachlorophenol
PSD	particle size distribution
ppb	parts per billion
ppm	parts per million
psi	pounds per square inch
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
RREL	Risk Reduction Engineering Laboratory
SARA	Superfund Amendments and Reauthorization Act of 1986
SEM	scanning electron microscope

Abbreviations and Symbols (Continued)

SITE	Superfund Innovative Technology Evaluation Program
TCLP	Toxicity Characteristic Leaching Procedure
TMSWC	Test Methods for Solidified Waste Characterization
TOC	total organic carbon
TSCA	Toxic Substances Control Act
UCS	unconfined compressive strength
µm	micrometer
µg/L	micrograms per liter
VOC	volatile organic compound
XRD	X-ray diffraction
yd^3	cubic yard

Conversions

	English (US)	Metric (SI)
Area:	1 ft^2	9.2903×10^{-3} m^2
	1 in^2	6.4516 cm^2
Flow Rate:	1 gal/min	6.3090×10^{-5} m^3/s
	1 gal/min	6.3090×10^{-2} L/s
	1 Mgal/d	43.8126 L/s
	1 Mgal/d	3.7854×10^{3} m^3/d
	1 Mgal/d	4.3813×10^{-2} m^3/s
Length:	1 ft	0.3048 m
	1 in	2.54 cm
	1 yd	0.9144 m
Mass:	1 lb	4.5359×10^{-2} g
	1 lb	0.4536 kg
Volume:	1 ft^3	28.3168 L
	1 ft^3	2.8317×10^{-2} m^3
	1 gal	3.7854 L
	1 gal	3.7854×10^{-3} m^3

ft = foot, ft^2 = square foot, ft^3 = cubic foot
in = inch, in^2 = square inch
yd = yard
lb = pound
gal = gallon
gal/min = gallons per minute
Mgal/d = million gallons per day
m = meter, m^2 = square meter, m^3 = cubic meter
cm = centimeter, cm^2 = square centimeter
L = liter
g = gram
kg = kilogram
m^3/s = cubic meters per second
L/s = liters/second
m^3/d = cubic meters per day

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Section 1
Executive Summary

Introduction

In 1986, the EPA established the Superfund Innovative Technology Evaluation (SITE) Program to promote the development and use of innovative technologies to clean up Superfund sites. The analysis of the technologies in the SITE Program are contained in two documents, the Technology Evaluation Report and this Applications Analysis Report. This report evaluates and estimates the applicability and costs of the International Waste Technologies (IWT)/Geo-Con in situ stabilization/solidification process based on all available data. This data, other than the demonstration, is from laboratory studies.

The most extensive testing of the combined technologies was performed during the SITE demonstration, based upon an agreed to demonstration plan between EPA and the developers, although other information on the individual technologies is provided by the developers. EPA used a direct approach to evaluate the technology by measuring contaminant mobility and solidified mass durability. The emphasis of the IWT research work has been to show that chemical bonding of additive to contaminant occurs. However, this is only an indirect approach, and it requires a research program that is outside the scope of a SITE project.

The demonstration occurred at a General Electric Co. (GE) electric service shop in Hialeah, Florida in April 1988. The process involves the in situ injection and mixing of the IWT additive HWT-20 with the hazardous waste material. IWT claims that HWT-20 chemically bonds to the PCB contaminants, thus immobilizing them and containing them within a hardened, leach-resistant concrete-like mass. Therefore, the major objectives of the SITE project were to evaluate the IWT/Geo-Con in situ stabilization/solidification technology in the following areas:

- Immobilization of polychlorinated biphenyls (PCBs) -- mainly Aroclor 1260, a set of congeners of known ratio.
- Immobilization of organic and heavy metal contaminants, based on other experience of the developers.
- Demonstration of in situ operation of the Geo-Con soil mixing equipment.
- Degree of soil consolidation (solidification) caused by the chemical additive, HWT-20.
- Probable long-term stability and integrity of the solidified soil.
- Performance and reliability of the Geo-Con injection and mixing auger.
- Costs for commercial-scale applications.

Conclusions

The conclusions drawn from reviewing the data on this in situ stabilization/solidification process, both from the SITE demonstration and other available data in relation to SITE project objectives were:

- PCBs do appear to be immobilized by the process. However, for most of the tests, the PCB concentrations in the soil and resulting leachate concentrations were low and so close to the analytical detection limits that a firm, decisive evaluation of the technology's ability to immobilize PCBs could not be performed.
- From laboratory studies provided by IWT, immobilization of volatile and semi-volatile organics may occur in some instances. This is based on TCLP leach tests, see Appendix D Case study D-4. In addition, the IWT additive contains organophilic clays, which are known

in some cases to bond to organics. However, since insufficient data exists, both from the demonstration and these laboratory studies, confirmation of immobilization is not possible.

- IWT data indicates that the HWT compounds probably immobilize heavy metals. This is supported by the fact that most cement-based systems can immobilize metals.

- The PCB concentrations in the soil at the Hialeah site were too low for effective evaluation of this technology. Thus, bench scale testing of samples by EPA with higher concentrations of PCBs would have enhanced the evaluation of the IWT additive. Later, such treatability studies were added to the SITE demonstrations.

- The physical properties of the treated soils were in general quite satisfactory, which would support the potential for long-term durability. High unconfined compressive strengths (UCS) (300-1,000 psi), low permeabilities (10^{-6} to 10^{-7} cm/s), and satisfactory results of the wet/dry weathering tests were obtained. Many of the freeze/thaw test specimens showed large weight losses and samples degraded sharply. However, IWT has indicated that the additive mixture used in the demonstration was designed for Florida, where freeze/thaw weathering should not be a problem. The volume increase of the soil after treatment was small, about 8.5% in the demonstration. The microstructural analyses of solidified soil samples indicated a potential for long-term durability; the samples showed a dense, homogeneous, and low-porosity structure. The apparent disagreement between the poor freeze/thaw results (taken only during the demonstration) and the other satisfactory results cannot be explained at this time.

- The Geo-Con deep-soil-mixing equipment appeared to work well during the demonstration and provided intimate mixing of additive and soil. Geo-Con also has other experience at hazardous waste sites, where sludge ponds were solidified and barrier walls provided, as well as considerable soil consolidation experience in all types of soils. Thus, the deep-soil-mixing capabilities of Geo-Con are well proven.

- The IWT/Geo-Con in situ stabilization/solidification system is economical. Remediation costs for two cases were estimated. For the first case, using Geo-Con's larger 4-auger system, under the ground rules defined in Section 4, the cost was $111/ton of soil. For the 1-auger unit, used during the demonstration, the cost was $194/ton of soil.

It appears possible to apply the IWT/Geo-Con technology for immobilization of heavy metals, PCBs and some heavy organics in wastes up to 25 wt% organics. Although an HWT-20 admix was selected for use at the Hialeah site for the treatment of PCB-contaminated soils, other formulations exist to treat other contaminants. However, since very limited bench-scale studies have been performed, it is recommended that treatability studies -- site specific leaching, permeability, and physical tests -- be performed on each specific waste to be treated.

The Geo-Con technology can be used for most soils in most climates with treatment capabilities to a depth in excess of 100 ft. However, clays, oily sands, and cohesive soils may reduce auger penetration rate and depth of operation.

Potential physical limitations in the application of the IWT/Geo-Con technology need to be considered. The volume increase may cause some difficulties in restricted site areas where land contours could be seriously altered. An additional limitation is the technology's use in cold climates, where freeze/thaw degradation of the solidified monolith may occur and the feed slurry may freeze during operation. Large rocks (> 10 in.) and man-made obstacles such as drums and lumber can provide hindrances.

Results

Chemical Tests

Chemical analyses were performed on untreated and treated soils, along with leaching tests for the corresponding soil sample. Leachate analyses exist: on treated and untreated soils from the demonstration, using the Toxicity Characteristic Leaching Procedure (TCLP); on Law Environmental (LE) samples taken at the GE site, using Extraction Procedure Toxicity (EP Tox) and TCLP; and from some testing performed by IWT on PCBs, VOCs, heavy metals, and semivolatile organics, using TCLP.

The IWT process, as evaluated during the demonstration, appears to immobilize PCBs. However, due to the relatively low levels of PCBs at the Hialeah site, which produced leachate concentrations close to their detection limits (0.1 µg/L), more information at higher PCB concentrations are required to confirm this conclusion. For laboratory prepared samples by LE using soils from the site known to have different concentration levels of PCBs, which ranged from 83 to 5,628 mg/kg, results from EP Tox tests showed immobilization. However, TCLP tests on 5 samples

showed higher concentrations in the leachates of treated soils than those of untreated soils. LE had no definitive explanation for the unexpected results. Thus, the LE results also provide some uncertainty on the ability of the process to immobilize PCBs.

The demonstration was inconclusive on the ability of the process to immobilize VOCs and metals, due to an insufficient number of samples available for testing. In addition, IWT did not tailor its HWT-20 additive to immobilize VOCs and metals, but did design it for PCBs. IWT has performed some TCLP tests on treated samples prepared in the laboratory, and considerable laboratory testing using solvent extraction, Fourier transform infrared (FTIR) and differential scanning calorimetry (DSC). These latter tests were to prove that the additive chemically bonds to various organic and inorganic compounds. It does appear that some bonding occurs, which would in all likelihood reduce contaminant mobility. Chemical bonding should also reduce the need for maintaining physical integrity of the solidified monolith.

Physical Tests

The most extensive physical testing carried out to date on the IWT process was performed as part of the SITE demonstration, although some additional data was obtained by LE [1] for GE on laboratory prepared samples and from core samples taken shortly after the demonstration [2]. All of the available test data are based on a soil with a very low organic content, i.e., a very narrow range of contaminated soils. IWT cannot provide any other data; their research emphasis is related almost exclusively to chemical bonding studies, which they claim show the capabilities of their additives better than physical tests.

During the demonstration, unconfined compressive strength (UCS) values ranged from a low of 75 psi in Sector B to a high of 866 psi in Sector C, with the overall average about 400 psi. The tests performed by LE produced UCS values ranging from 198 to 2,127 psi for approximately the same dosage rate of HWT-20. These are very satisfactory when compared to the EPA guideline of a 50-psi minimum [3] for stabilization/solidification systems and other concrete-based waste-treatment systems, which have UCS results typically in the range of 15 to 150 psi [4]. However, there are a few other technologies that do provide larger values of UCS. High UCS values imply the potential for maintaining structural integrity.

The results from the 12-cycle wet/dry and freeze/thaw weathering tests showed low absolute weight losses for the wet/dry samples (0.3% to 0.4%). However, for the freeze/thaw test specimens, weight losses up to 30% were seen, with an average of 6.3%, while the control sample weight losses were about 0.3%. UCS tests on the weathered samples from the SITE demonstration showed no loss of strength when weight losses were less than 3.0%. Above 3.0%, very severe strength losses were measured, with UCS values approaching zero at 10% weight loss. These weathering tests are more severe than weathering under an actual field environment, but do provide an indication of short-term durability, since the tests only consist of 12 cycles. IWT has indicated that they can adjust the additive mix to be more resistant to freeze/thaw conditions. Quantification of solidified mass integrity in terms of life expectancy is not possible.

Permeability is a measure of a solid's ability to permit the passage of water. The treated soil values obtained for the SITE demonstration were between 10^{-6} and 10^{-7} cm/s, and they are slightly greater than those obtained by LE and EPA on samples prepared by LE. These values are comparable to the target value of 10^{-7} cm/s or less used for designing soil barrier liners for hazardous-waste landfill sites. Also, this is a large decrease compared to the untreated soil (10^{-2} cm/s) and indicates the groundwater will flow around the treated block. Low permeabilities should reduce the potential for both erosion and leaching.

Bulk density results were obtained for the SITE demonstration as well as for some earlier samples prepared by LE for GE. The bulk density increase on solidification averaged 21%, from 1.55 g/mL (96 lb/ft^3) to 1.88 g/mL (117 lb/ft^3), for a total mass increase (HWT-20 plus water) of 32%, which resulted in a volume increase of 8.5%. Even though this volume increase is relatively small, the ground rise could require removal of treated soil or special site contouring. Only posttreatment values are available from the LE tests and they tend to agree with the demonstration results, showing a bulk density of about 1.83 g/mL (114 lb/ft^3).

The microstructual analyses performed on SITE demonstration samples included optical and scanning electron microscopy and X-ray diffraction analyses of the crystalline structures. These results showed a dense, homogeneous, and nonporous structure. Therefore, a potential for long-term durability of the treated soil monolith exists.

Operations

Geo-Con, Inc. performed the remedial operations for the demonstration in two 10x20-ft test sectors. They were responsible for the slurry preparation, flow control of additive and water, and soil injection and mixing. Equipment operations were satisfactory. Some minor operating problems occurred, such as: inability to maintain automatic feed control; losing supplemental water for the last 21 soil columns due

to a leak in the auger head; and the locations of many of the soil columns deviated from the targeted location, producing some poorly treated areas. However, these difficulties are readily fixable. Geo-Con also has very considerable experience in soil consolidation, constructing slurry barrier liners and work similar to that at Hialeah in all types of soils to depths in excess of 100 ft. Overall, the conclusion is that Geo-Con's injection and mixing equipment provides a unique technology that can be considered a valid option where in situ stabilization/solidification or solidification technologies are deemed desirable.

Economics

The economic analysis investigated two cases, one using a 1-auger machine as in the demonstration, and the other with a 4-auger unit, which would be used for large-scale operations. Only one additive rate was assumed, 0.15 lb HWT-20/lb dry soil, which is near the minimum that IWT would use for any remediation. Most of the operating expenses were provided by Geo-Con, based on their quotation to GE.

The results, based on a 5 d/wk, 8 h/d operation and the simplified concepts defined in Section 4, showed the costs would be $111/ton of soil for the 4-auger unit and $194/ton of soil for the 1-auger unit. The cost components with the most impact on the totals were equipment rental, the HWT-20 additive, and labor, which combined, amounted to about 85% of the total cost.

Section 2
Introduction

The SITE Program

In 1986, the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established the Superfund Innovative Technology Evaluation (SITE) Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. The SITE Program is composed of two major elements: the Demonstration Program and the Emerging Technologies Program.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data on selected technologies. To date, the demonstration projects have not involved EPA funding for technology developers. EPA and developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing, and evaluating all test results. The result is an assessment of the technology's performance, reliability, and cost. This information will be used in conjunction with other data to select the most appropriate technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. To qualify for the program, a new technology must be at the pilot or full scale and offer some advantage over existing technologies. Mobile technologies are of particular interest to EPA.

Once EPA has accepted a proposal, EPA and the developer work with the EPA regional offices and state agencies to identify a site containing wastes suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to thoroughly evaluate the technology and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several months, depending on the length of time and quantity of waste needed to assess the technology. After the completion of a technology demonstration, EPA prepares two reports, which are explained in more detail below. Ultimately, the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

SITE Program Reports

The analysis of technologies participating in the Demonstration Program is contained in two documents, the Technology Evaluation Report and the Applications Analysis Report. The Demonstration Report contains a comprehensive description of the demonstration sponsored by the SITE program and its results. This report gives a detailed description of the technology, the site and waste used for the demonstration, sampling and analysis during the test, and the data generated.

The purpose of the Applications Analysis Report is to estimate the Superfund applications and costs of a technology based on all available data. This report compiles and summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations of the technology. Costs of the technology for different applications are estimated based on available data on pilot- and full-scale applications. The report discusses the factors, such as site and waste characteristics, that have a major impact on costs and performance.

The amount of available data for the evaluation of an innovative technology varies widely. Data may be limited to laboratory tests on synthetic wastes, or may include performance data on actual wastes treated at the pilot or full scale. In addition, there are limits to conclusions regarding Superfund applications that can be drawn from a single field demonstration. A successful field demonstration does not necessarily assure that a technology will be widely applicable or fully developed to the commercial scale. The Applications Analysis attempts to synthesize whatever information is available and draw reasonable conclusions. This document will be very useful to those considering the technology for Superfund cleanups and represents a

critical step in the development and commercialization of the treatment technology.

Overview of Stabilization/Solidification

Stabilization and solidification are treatment processes designed to accomplish one or more of the following:

- Improve the handling and physical characteristics of the waste.
- Decrease the surface area of the waste mass.
- Limit the solubility of hazardous constituents.
- Detoxify contained contaminants.

Stabilization is a beneficial action that occurs through limiting the solubility or mobility of the contaminants irrespective of a change in physical characteristics. Solidification implies that a benefit is obtained through the production of a solidified block, which has high structural integrity.

Stabilization processes are grouped into categories according to the types of additives and processes used. These categories are: (1) cement, (2) lime plus pozzolan (fly ash, kiln dust, hydrated silicic acid, etc.), (3) thermoplastic (asphalt, bitumen, polyethylene, etc.), (4) thermosetting organic polymers (ureas, phenolics, epoxides, etc.), (5) vitrification, and (6) miscellaneous others. The existing processes, although assumed to be chemical in nature, involve little chemical alteration. The waste particles may merely be microencapsulated, which is particularly true for organic contaminants [5]. In situ stabilization/solidification is one variation on the above categories of treatment processes.

The IWT process is a cementitious process that also uses proprietary additives and other pozzolans. Portland cement reaction products are a fused mixture, in somewhat variable proportions of calcium, silicon, aluminum, and iron oxides, the main constituents of which are usually hydrated calcium alumino-silicates and calcium silicates. This type of process is usually most applicable to treating inorganic wastes, such as incinerator wastes and other sources of heavy metals. Usually the purpose of adding other pozzolans, such as fly ash, is to produce a stronger product. Organics (such as oil and grease) in the soil may interfere with the cement bonding reactions by coating the soil particles. At soil contents above 10 wt% interferences from organics may occur.

One possible approach that could reduce the mobility of organic contaminants in cemetitious systems is to use an additive that interacts with the cement matrix, while at the same time adsorbing the organic material. Clay minerals offer one such possibility and have been used for many years by the nuclear industry [6]. Of particular interest is the use of clays, reacted with alkylammonium cations (quaternary ammonium salts), to enhance clay-organic waste interaction. Although the actual composition of the IWT additive is proprietary information, it appears that its technology is similar to the approach using organophilic clays. In addition to the chemical bonding, IWT also claims that some of their additives break down the contaminant to harmless compounds.

Stabilization/Solidification Technologies and Superfund Response Actions

Section 121 (Cleanup Standards) of the Superfund Amendments and Reauthorization Act (SARA) of 1986 requires that remedies both be protective of human health and the environment, and be cost-effective. SARA states a strong preference for remedies that are highly reliable and provide long-term protection. The statute also states a preference for remedial actions that employ treatment that permanently and significantly reduces the volume, toxicity, or mobility of hazardous waste. Stabilization/solidification is one of the treatment technologies with the potential to meet the cleanup standards.

Stabilization/solidification has been selected at numerous Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) sites to reduce waste toxicity or mobility. (The SITE program demonstration of the IWT and Geo-Con technologies was conducted at a closed electrical service shop in Hialeah, Fla., which was not a CERCLA site.) A comprehensive list of sites for which stabilization/solidification has been chosen is beyond the scope of this document. However, this section discusses some of the general trends in the use of these technologies for CERCLA actions, gives some examples of site remediations involving stabilization/solidification and discusses the potentially applicable or relevant and appropriate requirements (ARARs) for the use of stabilization/solidification at CERCLA sites.

Use of Stabilization/Solidification

Both immediate removal activities and remedial actions under the CERCLA program have used or will use some type of stabilization/solidification. Between fiscal years (FY) 85 and 88, at least nine removal actions involved stabilization/solidification, usually using lime or kiln dust to treat waste sludges. As of the end of FY88, stabilization/solidification had been selected as a cleanup remedy in 38 Records of Decision (RODs) for

National Priorities List (NPL) sites. Eighteen of these RODs were signed in FY88.

Of the CERCLA sites for which stabilization/solidification has been selected or used, the method has typically been applied to wastes (usually sludge, sediment, and surrounding soil) that are acidic or contain heavy metals. For instance, stabilization/solidification was selected to treat soil and sediments contaminated with metals at the following NPL sites: Sapp Battery in Florida, Marathon Battery in New York, and Independent Nail in South Carolina. As the use of incineration increases, stabilization/solidification may be selected to treat residual ash, if the ash requires further treatment to reduce the mobility of metals prior to redisposal onsite. This application of stabilization/solidification was chosen for the Geiger (C&M Oil) site, South Carolina. Stabilization has also been selected to treat soil contaminated with radioactive waste at the Denver Radium site in Colorado.

In addition, stabilization/solidification has been selected to treat wastes containing organic compounds. In an application similar to Hialeah, in 1986, stabilization/solidification was selected in the ROD for the Pepper Steel and Alloys, Inc. site in Florida for treatment of soil contaminated with PCBs and heavy metals. The cleanup occurred in 1988, when the soil was excavated, separated from debris, and mixed with Portland cement before being returned to the excavated area of the site. Like the Hialeah site, the site is sandy and overlies a shallow aquifer (4 to 5 ft below land surface). Other sites where stabilization/solidification was selected to treat organics include: York Oil in New York, to treat soil and sediment contaminated with metals, petroleum hydrocarbons and low concentration of other organics, including PCBs; Fields Brook in Ohio, to treat sediments containing metals and organics, including PCBs; Liquid Disposal Landfill in Michigan, to treat soil and waste containing heavy metals and organics, including PCBs; Industrial Waste Control in Arkansas and Bailey Waste Disposal in Texas, to treat soil containing organics; and Chemical Control in New Jersey to treat soil containing heavy metals and organics.

To date, no CERCLA cleanup has selected the in situ application method offered by IWT and Geo-Con and tested in this SITE demonstration. In most of the examples listed above, the application method for the stabilization/ solidification reagents was not specified in the ROD and was to be addressed in the design phase of the remedial action. The two most frequent types of stabilization/solidification treatment are bulk mixing in a pit and excavation and treatment in a tank. However, in situ stabilization/solidification was specified in the ROD for the Chemical Control site because of the small size of the site and other engineering difficulties.

Role of Stabilization/Solidification in the Future

Currently, many stabilization/solidification vendors use additives (such as dispersants and organophilic proprietary compounds) in conjunction with setting agents to improve the ability to bind organics to the solid product. Because of the availability of these new mixtures, stabilization/solidification may be considered more frequently to treat soil contaminated with organic compounds, alone or together with metals. In addition to the IWT and Geo-Con technologies, the SITE program is evaluating stabilization/solidification methods offered by five other vendors. These additional demonstrations all involve soil and sludge containing organic compounds as primary contaminants, such as solvents, PCBs, petroleum hydrocarbons, and coal tars. The demonstration of the IWT and Geo-Con technologies is the only SITE project to date involving in situ stabilization/solidification.

Evaluation of the effectiveness of available stabilization/solidification processes for a specific site and waste requires bench-scale testing, in which small samples of the waste and reagents are mixed and allowed to cure. The treated samples are then subjected to physical and chemical tests such as those described in Section 3 of this report. Bench-scale tests can also assess the potential for emissions of volatile compounds during the mixing process, which often involves the release of heat during reactions between the waste and the additives. Bench-scale testing of stabilization/solidification is currently being implemented during the feasibility study and design phases at many CERCLA sites. It should be noted that the tests available to evaluate this technology do not directly measure its long-term effectiveness.

Regulatory Considerations

CERCLA Section 121(d) requires onsite Superfund remedial actions to comply with federal, and more stringent state environmental requirements that are determined to be ARARs. The current NCP requires onsite removal actions to comply with federal ARARs to the extent practicable. Two sets of federal regulations that are potential ARARs for in situ stabilization/solidification of PCB waste are the Land Disposal Restrictions (LDRs) under the Resource Conservation and Recovery Act (RCRA) and the PCB waste disposal regulations under the Toxic Substances Control Act (TSCA). The regulatory requirements are discussed in more detail in Section 3 of this report. Regardless of which

regulations are ARARs, all Superfund cleanups must be protective of human health and the environment.

Stabilization/solidification is not now considered a best available demonstrated technology (BDAT) for a RCRA hazardous waste that contains organic contaminants and is subject to the LDRs. OSWER Directive 9347.1-02 (Apr. 17, 1989) states that for the LDRs to be applicable, the CERCLA response action must constitute placement of a restricted RCRA hazardous waste. Placement does not occur if wastes are moved within a unit or are left in place. Therefore, in situ treatment, such as for the stabilization/solidification process using IWT and Geo-Con technologies, does not involve placement, and the LDRs are not applicable.

Key Contacts

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Section 3
Technology Applications Analysis

Introduction

This section of the report addresses the applicability of the IWT in situ stabilization/solidification technology using the Geo-Con/DSM equipment to remediate various feedstocks based on the results of the SITE demonstration and other IWT and Geo-Con data. Since the results of the demonstration provide the most extensive database available, conclusions on the effectiveness of the process and its applicability to other potential cleanups will be strongly influenced by those results. These are presented in detail in the Technology Evaluation Report. Additional information on the IWT and Geo-Con technologies -- including a process description, vendor claims, a summary of the demonstration results, and summaries of outside sources of data -- are provided in Appendices A-D.

To evaluate the combined technologies of IWT and Geo-Con, the following technical criteria were used:

- Ability of the IWT additive to immobilize PCBs and other contaminants.
- Durability of the solidified, treated soil mass -- which is indicated by results obtained from many of the physical property tests.
- Ability of the Geo-Con DSM equipment to blend a cementitious additive with contaminated soil.

Following are the overall conclusions being drawn on the IWT and Geo-Con technologies. The Technology Evaluation subsection discusses the available data from the demonstration and IWT studies. It also provides more detailed conclusions and discussion of applicability of the IWT and Geo-Con in situ stabilization/solidification process. This is followed by subsections covering federal regulations, waste characteristics and performance of the technology, materials handling, personnel issues and procedures for evaluating stabilization/solidification.

Conclusions

The conclusions stated for this in situ stabilization/solidification technology are drawn primarily from the demonstration, but were also supplemented by information provided by IWT and LE on laboratory studies. The conclusions are:

- PCBs do appear to be immobilized by the process, based upon TCLP leach test and physical test results. However, for most of the tests, PCB concentrations in the soil were relatively low (<500 mg/kg), and the leachate concentration levels were low and very close to the analytical detection limits. Thus, confirmation of this conclusion is not possible. In addition, the data that IWT provided were for posttreatment soil leachates only and a determination of immobilization is not possible.

- From laboratory studies provided by IWT (both leach tests and more sophisticated tests to prove chemical bonding) immobilization of volatile and semivolatile organics appears possible, but since pretreatment leach tests were not performed, confirmation is not possible. The demonstration did not provide sufficient data points to allow any conclusions to be drawn. (IWT claims that their additive was not designed for VOCs.) However, IWT claims the HWT-20 additive contain organophilic clays, and the literature [6] indicates that bonding of organics to some treated clays does occur, thus immobilization appears possible.

- Immobilization of heavy metals is probable. However, insufficient data are available from IWT or the demonstration to provide confirmation. Cement-based systems are usually effective on heavy metals, and the reported treated soil leachates for the IWT technology are low -- in most cases less than 100 µg/L.

- IWT's primary study efforts are to develop additives that chemically bond to the contaminants, and most of its test work is related to confirming this. However, the demonstration was not designed to prove this, thus no conclusions related to chemical bonding are offered.

- Physical properties of treated soil samples -- in each case for samples of very low organics content (<1.6 wt%) -- were generally satisfactory, except for the freeze/thaw weathering tests, which were performed only during the demonstration. The UCS values were high (300-500 psi), the permeabilities were satisfactory (10^{-6} to 10^{-7} cm/s), and the volume increase, due to the addition of HWT-20 additive, was low -- about 8.5% during the demonstration. The microstructural analyses showed a dense, homogeneous and low-porosity structure, which with the other results obtained (if the freeze/thaw difficulty can be corrected by IWT as they claim) indicates that the solidified mass has the potential for long-term durability. These physical results, where comparisons can be made, are approximately equivalent to test results where cement was substituted for HWT-20 during the demonstration.

- The Geo-Con/DSM equipment appears to work well and to provide intimate mixing of additive and soil. Geo-Con and various Japanese vendors have used in situ injection to consolidate soils, construct slurry cut-off walls, etc. in all types of soils, thus, the equipment has a proven capability of use in a wide variety of soils and applications.

Applications of this in situ process for immobilization of PCBs, heavy metals and volatile and semivolatile organics at low organics content in the soil seems possible especially for the heavy metals. Even for high-organic-content wastes -- up to 25 wt% -- immobilization may be possible. However, physical properties of treated soil in cement-based systems start to deteriorate at about 10 wt% organics in the untreated soil. Therefore, since only very limited bench-scale studies have been performed and there is no field work at the higher organic levels, it is recommended that treatability studies (for both chemical and physical characteristics) be performed on each waste, whether low or high in organic content

As for the use of the Geo-Con DSM equipment, few limitations appear to exist. The DSM equipment, and similar units in Japan, can operate in most soils and in most climates, to a depth of more than 100 ft. However, some limitations may exist:

- A volume increase is expected which may cause difficulties in restricted areas where land contours would be seriously altered. Also, for high-organic-content wastes, where the IWT additive rate would be increased, the larger volume increase would be of even more concern.

- Soil debris, such as large rocks and buried drums, would probably have to be excavated before auger injection. Special injection equipment should be used for deeper obstacles.

- Very low ambient temperatures (below 10°F) may cause freezing of the feed slurry before injection.

Evaluation of Performance

The criteria defined in the SITE Program Demonstration Plan [7] to evaluate the IWT and Geo-Con in situ stabilization/solidification technology are:

- Immobilization of PCBs as determined from leaching and permeability tests.

- Long-term durability of the solidified soil, as determined from various physical tests such as UCS, weathering (wet/dry and freeze/thaw), and microstructural analyses (microscopy and X-ray diffraction).

- Reliability and versatility of the mechanical equipment.

The above criteria are a direct approach to the evaluation of the effectiveness of the technology before and after treatment. A separate research project to support the IWT findings of chemical bonding between additive and contaminant was outside the scope and intent of the commercial scale SITE demonstration. The reaction mechanisms do help to explain the direct results obtained and also provides insight for extending the results to other applications. A separate research program would have complemented the demonstration. The following discussions, using the available IWT and Geo-Con information, will provide more detailed conclusions on the process, particularly as related to the various physical and chemical properties of the treated soil.

Chemical Test Results

The chemical analyses of soil and leachates, provide information in evaluating the immobilization of the various contaminants. Leaching tests indicate the chemical stability of the solidified mass [8], its tendency to leach by water, and the mobility of contaminants contained in the solidified waste when they are in contact with aqueous solutions. To properly evaluate immobilization, both pretreatment and posttreatment soil and leachate analyses are required. The most extensive chemical analyses, measuring both the waste and leachate compositions, before and after treatment, were

performed as part of the SITE demonstration. Data are also available from laboratory studies of IWT and from the laboratory formulation studies by LE for GE, using electric-service-shop soil. Most of this work was related to PCBs, although some laboratory studies were performed by IWT on metals, volatile organics, and semi-volatile organics. Since it is important to know the quantity of the contaminants in the untreated and treated wastes when performing a leach test, the most complete information is available from the demonstration where both analyses were performed. Some before and after treatment leach test results were performed by LE [1].

During the demonstration, the IWT in situ stabilization/solidification process appeared to immobilize the PCBs, which are relatively immobile contaminants, even without treatment. Unfortunately, due to the relatively low levels of PCBs measured in the soil at the Hialeah site (maximum 950 mg/kg untreated and 170 mg/kg treated) during the test, which produced leachates close to their detection limit (0.1 µg/L), more information at higher PCB concentrations in the wastes is required to confirm immobilization.

Law Environmental treated in the laboratory soil samples containing 83, 1,130, and 5,628 mg/kg PCBs in the untreated soil, with varying amounts of HWT-20 -- from 0.05 to 0.25 lb/lb dry soil (see Appendix D-1). Four different leach tests were performed on both the untreated and treated soils -- three versions of the Extraction Procedure Toxicity (EP Tox), and the Toxicity Characteristic Leaching Procedure (TCLP). One EP Tox test version used the standard membrane filter; prior experience has shown that PCBs absorb onto the filter and provide low, erroneous values. The other two versions used a glass fiber filter, one using site water and sulfurous acid to reduce the pH to 5.0, and the other using the standard acetic-acid leach medium.

The results of these tests showed the following:

- For the low-PCB-concentration soils, untreated-soil leachate values, using only the standard EP Tox with a membrane filter, were below the detection limit (1.0 µg/L).

- For the medium-PCB concentration soils (1,130 mg/kg), 58% to 94% concentration reductions (using the glass fiber filter) were seen, with the treated-soil leachate concentrations in the range 2.6 to 10.0 µg/L. These values did not relate to the additive rates, which were in a narrow range of 0.15 to 0.18 lb/lb dry soil.

- For the high-PCB-concentration soils (5,628 mg/kg), 0% to 90% concentration reductions (using the glass fiber filter) were seen, with the treated-soil leachate concentrations in the range <1 to 98 µg/L. The treated soil leachate value of 98 µg/L was with an additive rate of 0.05 lb/lb dry soil. At the higher additive rates of 0.15 and 0.25 lb, the leachate values ranged from <1 to 32 µg/L, which is a concentration reduction of 51% to 90%.

- For the TCLP results, the treated-soil leachate values for all five samples -- from low to high soil-PCB levels -- were greater than the untreated-soil leachate values. LE had no confirmed explanation for this, and suggested that possibly the leaching fluid (Fluid #2 with a pH of 2.8) was the cause. The TCLP was developed to overcome the shortcomings of EP Tox for the leaching of organics, and therefore, it would be expected to provide more satisfactory results. Nevertheless, based on available leach test results, the studies performed by LE for GE using HWT-20 did not show immobilization of PCBs.

For each of the three EP Tox tests, LE found a relationship between the PCB concentration in the leachate and the ratio of HWT-20 additive to water. It found the curve went though a minimum at an additive-to-water ratio of 1.0-1.5. This result was likened to the optimum moisture content for cement, which might tend to confirm the validity of the EP Tox results versus the TCLP values.

In a second group of samples, LE mixed HWT-20 as a slurry with the soil, instead of mixing it dry. The additive was mixed in concentrations of 0.12 to 0.20 lb/lb dry soil. Untreated soil concentrations of PCBs were in the range of 893-3,944 mg/kg. Treated soil leachates (using EP Tox with glass fiber filter) ranged from 2.4-4.5 µg/L. One untreated soil sample with a PCB concentration of 5,719 mg/kg had a leachate concentration of 11.0 µg/L. A table of results is included in Appendix D.

If the TCLP results are discarded, the EP Tox results from the LE work show immobilization of PCBs. However, based on the LE report, there is not a valid reason to eliminate the TCLP results. Thus, the LE work is inconclusive on the ability of HWT-20 to immobilize PCBs. See Appendix D-1 for more detailed information.

IWT performed some laboratory experiments before the demonstration. One was at very high PCB concentrations in a soil like at Hialeah -- 28,800 mg/kg -- the other at a moderate value -- 290 mg/kg -- the same order of magnitude as some untreated soils in the demonstration. After treatment for the high concentration soil -- 0.20 lb HWT-20/lb dry soil -- only 10 wt% PCB could be extracted by methylene

chloride solvent. In addition, IWT reported a TCLP leachate value of 12.5 mg/L, and very high levels of chlorinated benzenes in the soil, which they attributed to the decomposition of PCBs. In the other test, the additive rate was 0.15 lb and only two-thirds of the PCBs could be extracted by a solvent. Also, volatile organics measured in the untreated soil were not detected in the treated soil. Thus, it was concluded by IWT that HWT-20 was bonded to the PCBs, which seems a reasonable possibility. It should be noted that the only chlorinated benzene (chlorobenzene) measured during the demonstration existed in the same proportion to the other VOCs in both the untreated and treated soil, so this IWT observation was not confirmed.

During the demonstration, GE collected and analyzed samples from two locations in Sector B and two locations just south of Sector B. The samples outside the sector (by 1 ft and 2 ft) showed no consolidation, indicating that the HWT-20 additive did not spread beyond the test sector, and leach tests were not performed. For the other two groups of samples, one was near Sample Location B-20 in an area where column overlap (see Appendix A for more information) was poor and the other was near Sample Location B-21. Samples were collected at six depths (maximum 17 ft) at each location. These treated soil samples were analyzed for PCBs. TCLP leach tests were performed approximately 3 weeks after the soil samples were collected, thus allowing a 3-week curing period. The results are shown in Table 1, with a summary of the data sheets from the laboratory report provided in Appendix D-3.

Table 1. Posttreatment Soil and Leachate Analyses of Samples Collected by GE

Location near	Depth, ft	PCBs in soil, mg/kg	PCBs in TCLP leachate, µg/L
B-21	3.0 - 3.6	34.9	1.20
B-21	5.0 - 5.75	182.0	<0.10
B-21	7.0 - 7.8	206.0	0.22
B-21	9.5 - 11.0	166.0	0.12
B-21	12.5 - 14.0	32.9	<0.10
B-21	15.5 - 17.0	13.7	0.11
B-20	1.5 - 3.0	22.8	<0.10
B-20	3.0 - 4.5	47.7	<0.10
B-20	6.0 - 7.4	72.7	<0.10
B-20	7.4 - 9.0	57.4	<0.10
B-20	10.5 - 12.0	2.0	<0.10
B-20	13.5 - 15.0	1.0	<0.10

In the area where treated soil columns overlapped poorly, the PCB concentration in the soil ranged from 1.0 to 72.7 mg/kg, with the maximum value at a depth of 6.0-7.5 ft. All corresponding leachate results were below the detection limit of 0.1 µg/L. For the samples near Location B-21, where the overlap was satisfactory, the PCBs in the soil ranged from 13.7 to 206 mg/kg, with the maximum value at a depth of 7.0-7.8 ft. In this area, the PCB concentrations in the TCLP were above the detection limit at 4 of the 6 depths. The maximum TCLP leachate-concentration was 1.2 µg/L at a depth where the soil concentration was about 35 mg/kg PCBs. The next highest leachate value was 0.22 µg/L, which occurred for soil at the highest concentration value. At the second-highest soil value of 182 mg/kg PCBs, the leachate concentration was below the detection limit. These results showed that the more properly treated soil, although higher in PCB concentrations, showed detectable quantities of PCB in the TCLP extracts, while for the area of poor overlap, all leachates had PCB concentrations below detection limits. The data are similar to the demonstration values and, although very low, do not clarify whether the IWT process immobilized PCBs.

Prior to the demonstration, EPA performed tests on samples previously prepared by LE as a preliminary evaluation of the technology. The 3 samples tested had PCB concentrations ranging from 4,100 to 5,700 mg/kg. They were prepared from a batch of untreated soil with a PCB concentration reported by LE as 5,628 mg/kg. This indicated that the HWT-20 neither degraded or bonded to the PCBs. The 3 TCLP leachates each had PCB concentrations below the detection limit of 1.0 µg/L, which would support the possibility of PCB immobilization.

Thus, using all available sources, it appears that some data show immobilization of PCBs, while other data are inconclusive. Therefore, although it appears that the IWT additives may immobilize PCBs, the results are not conclusive.

Additional information is provided by IWT on various laboratory studies it has performed, which were presented in informal papers it has distributed. A copy of the most recent one was provided for the Vendor Claims section, Appendix B. Other papers are summarized as Appendices D-4 and D-5. The results presented provide various TCLP leachate results, after treatment only, for volatile organics, semi-volatile organics and heavy metals. In addition, tests using hexane and methylene chloride extractions were performed, to show that bonding of the contaminants to the additive occurred. If the organic contaminants are chemically bonded to the additive, the ability to extract them, even with an efficient solvent, is reduced. It would then follow that these organics may be immobilized.

Many examples are cited by IWT on its ability to immobilize volatile and semivolatile organics. In most cases, wastes containing up to 10,000 mg/kg of

an individual organic were reduced to less than 2 mg/L, with many values below detection limits. However, the detection limits are not defined, and corresponding values for untreated waste leachates do not exist. If the detection limits were tens or hundreds of parts per billion, then immobilization may have occurred. In one example, where the waste contained 26,500 mg/kg xylenes, the leachate value was 4,605 mg/L, which is very high. After adjusting the additive formulation, the value was reduced to 48 mg/L, which is still large and may not differ significantly from a TCLP leachate value for untreated waste. Thus, the ability of the IWT additive to immobilize VOCs or semivolatiles cannot be clearly determined from the limited leach test data available.

Leachate values for metals were below 1.0 mg/L in almost all cases reported, with most of them below 0.1 mg/L, which may meet existing regulatory standards for land disposal restrictions and delisting. However, in all tests, the concentration in the wastes was tens or hundreds of parts per million, which is not large. Since TCLP leachate values for untreated soils were not provided, except during the demonstration immobilization of the metals cannot be determined from the available data. However, most cement-based additives can immobilize heavy metals, so it is reasonable to believe the IWT additives also have the capability.

Chemical Bonding Tests--

Currently the most extensive studies by IWT, which were outside the scope of the demonstration, [9,10,11] are the tests to prove that its additive bonds to, or destroys, the organic contaminants (see Appendix D-6). If bonding occurs, even if the forces of attraction are weak, the mobility of the contaminant is reduced and the physical integrity of the treated waste may become less important, since bonding, as well as encapsulation, will prevent contaminant mobility. If this research is successful, the IWT technology might meet many of the current or potential regulations for both organics and metals (where reductions in the contaminant concentration in the wastes are measured). Various tests have been used in attempts to prove this claim, such as direct extraction with an organic solvent, Fourier transform infrared (FTIR), and differential scanning calorimetry (DSC). These tests, and the protocol to evaluate the process try to show bonding in the following manner:

Solvent Extraction--

During sample preparation for analyses of VOCs and semi-volatiles, the organics are extracted from the waste by hexane and the quantity is measured by gas chromatography/mass spectrometry (GC/MS). If bonding occurs, the solvent may not extract all of the contaminant and it will appear to have a reduced concentration level. If hexane does not extract the toxin, water in most cases will not either. The tests reported by IWT have shown reduced concentration levels of contaminants after treatment with HWT additives.

FTIR--Shifts in infrared vibrational frequencies of organic bonds occurred after treatment, showing a change in bond length between atoms. This indicates that weak bonding has occurred. Even weak bonding of this type should reduce the mobility of the contaminants.

DSC--This procedure measures the changes in temperature and energies required to release the contaminants from the soil matrix before and after treatment. If for example, the heat of vaporization increases, compared to the pure compound not in the solid matrix, as shown for the IWT additive [10], this indicates a bond may exist, restraining the release. IWT also claims that there is a breakdown in the organic molecules to smaller molecules, and that the energy for release of the organics increases. However, elevated temperatures are required when performing a DSC analysis, and clays (which are aluminosilicates related to zeolites, a known catalytic group) are known to catalyze many organic reactions. In proving chemical bonding or degradation, the key is whether these reactions occurred before heating; there is no evidence provided to this effect.

Evidence from solvent extraction and FTIR studies suggests that weak bonding probably occurs between many contaminants and the IWT additive. However, the basic IR spectra of the organics were observed in mixtures of HWT-20 and organics, with only modest frequency shifts. In addition, the extraction results of IWT showed only partial recovery of unaltered organics. However, the demonstration results and LE tests showed no evidence of PCB or VOC degradation. Thus, it is likely that the various IWT additives can reduce the mobility of many organic contaminants.

Physical Test Results

The physical tests -- UCS, weathering (wet/dry and freeze/thaw), and permeability -- provide information on the potential durability of treated waste. Permeability is also a strong factor influencing contaminant mobility. However, quantitative relations between the time the solidified mass can maintain its integrity and the test results (including microstructural observations) do not exist.

The most extensive physical testing on the IWT process was performed in the SITE project and reported in the Technology Evaluation Report [12]. This not only included the demonstration results, but

"screening test" results [13] on samples provided by LE to obtain a preliminary evaluation of the technology. The only additional information provided by IWT are data obtained by Law Environmental for GE in 1986 on laboratory prepared samples (using the same electric-service-shop soil) and from core samples taken from Sector B shortly after the demonstration. Thus, all physical test data are based on soil with a very low organic content from one small plant location. As a result, information on physical properties exists for only a very narrow range of contaminated soils.

Unconfined Compressive Strength--

Unconfined compressive strength is a primary indicator of durability of solidified wastes. The results of the samples taken from Sector B and C show very satisfactory strengths for the solidified material relative to EPA's guideline minimum of 50 psi [3] for stabilization/solidification systems. The results ranged from 75 to 579 psi in Sector B and 247 to 866 psi in Sector C. Results on laboratory prepared samples by LE, with additive concentrations between 0.10 lb HWT-20/lb dry soil and 0.25 lb HWT-20/lb dry soil, ranged from 198 to 2,127 psi (see Appendix D-2 for more details). The moisture contents of the laboratory-treated soil samples (2.8 wt%-13.6 wt%) were considerably lower than for the average of the field samples (18 wt%). The higher UCS values for the LE samples were at the higher moisture levels. The data does not show a definitive trend of UCS versus additive dosage rate at either high or low moisture content. It is possible that the samples with very low moisture content were incompletely hydrated, thus weakening the cement matrix. Another potential factor affecting UCS (not observed) is the degree of uniformity of the soil-additive mixing. This would probably favor the laboratory results, where the mixing should be better than that obtained in the field.

Three samples from a second batch of site soil, which were prepared by LE [14] using the additive in a slurry form (compared to the earlier formulations using dry additive addition), were tested by EPA during the Technology Screening Tests [13]. They produced UCS values of 418-1,185 psi for treated-soil moisture contents in the range of 8.6 wt%-16.1 wt%. Laboratory formulations during the demonstration by NUS Corp., the laboratory analyses contractor, using site soil -- with Type 1 Portland cement substituted for HWT-20 at 15 wt% and 20 wt% cement -- produced equivalent results at approximately the same moisture levels. Thus, the HWT-20 produces UCS values equivalent to using cement.

All these UCS results for soil with a very low organics content are quite satisfactory compared to the EPA guideline minimum of 50 psi. Cement-based waste treatment systems are typically in the range of 15-150 psi [4], although a comparison may not be fair without knowing the weight of additives used or the organics contents of the waste. High UCS values imply the potential for maintaining structural integrity for many years. In conclusion, the UCS values are quite good and indicate a potential for long-term structural integrity.

Permeability--

Permeability (also called hydraulic conductivity) indicates the degree to which the material permits the passage of water, and is thus one measure of potential for contaminants to be released to the environment. It would also be a factor in estimating the potential for long-term durability of the treated waste. Permeability depends on the solidified material's density, degree of saturation, and particle size distribution, as well as pore size, void ratio, interconnecting channels and the liquid pressure. Except for one value obtained by LE [13] and 3 values obtained during the EPA screening tests all values available are from the demonstration. The demonstration values averaged about 4×10^{-7} cm/s, while the screening tests averaged 2.7×10^{-8} cm/s, and the one value in the LE laboratory tests was 7.6×10^{-8} cm/s. Thus, it appears that the field data are an order of magnitude higher than the laboratory data. All the treated values are very low compared to the untreated soil values, which averaged about 3×10^{-2} cm/s. As a point of reference, cement systems usually can attain permeabilities of 10^{-5} to 10^{-6} cm/s [15]. Therefore, it is concluded that the IWT process can produce a solidified mass of low permeability, which is marginally acceptable when compared to the EPA criterion of 10^{-7} cm/s -- the value targeted for soil barrier liners for landfills used for hazardous waste disposal. In addition, this large decrease, compared to the untreated soil, indicates that the groundwater will flow around, not through, the treated block. Thus, if only one large mass is produced, the contaminants will remain isolated from the groundwater as long as the durability of the monolith is maintained.

Weathering--

Weathering effects can break down the internal structure of the solidified soil, producing potential paths for water flow, which would increase permeability and the potential for contaminant leaching and weaken the solidified mass. Weathering tests, which are more severe than field conditions in terms of the rate and degree of temperature change, only provide an indication of the short-term (12 cycles) treated-soil integrity in the face of natural weathering stresses. The tests are recommended as a means of comparing weathering performance of different processes, but cannot be

used to predict the long-term durability of solidified masses.

Twelve-cycle wet/dry and freeze/thaw tests were performed during the demonstration for all treated soil samples. The average of the cumulative relative weight-losses between test specimen and control for the 37 wet/dry tests was approximately 0.1%, with the absolute weight losses of the test specimens less than 0.4%. For the 38 freeze/thaw tests, the average cumulative relative weight loss was 6.3%, with the absolute weight loss of the control specimens approximately 0.3, the same as for the wet/dry tests.

Freeze/thaw weathering tests, although not of concern at the Hialeah site, are of concern in more northerly climates. The results are of concern because of the recognized potential for frost damage of concrete structures. The test uses a greater rate of cooling than the maximum of about 5°F/h that is expected in nature. In addition, the tests are carried out on specimens that are nearly water saturated, where the water can rapidly freeze and cause fracturing of the solidified waste, increasing the permeability of the solidified mass. Relatively dry concrete (such as that used for above-grade structures such as buildings) -- below 80% of saturation level -- is less likely to fracture than saturated material.

Tests for UCS were performed on approximately one-half of the test specimens and controls after the 12 weathering cycles. For all the controls and wet/dry specimens, the UCS results were comparable to the unweathered values. However, for the freeze/thaw test specimens, when the weight loss exceeded 3%, UCS values deteriorated, approaching zero at about 10% weight loss. Permeabilities performed on wet/dry and freeze/thaw test specimens showed no apparent increases compared to unweathered specimens, although freeze/thaw samples with high weight losses -- 10% and above -- were not tested.

Therefore, it can be concluded that the IWT process will maintain its integrity through wet/dry cycling. However, freeze/thaw cycling produces severe degradation of the solidified mass. Without formulation changes in the additive (which IWT claims they can accomplish), severe problems might be encountered with this process in cold climates. A scheduled long-term monitoring program exists, during which the treated soil will be sampled annually. This will provide additional information on durability of the solidified mass. The first long-term sampling occurred in April 1989.

Bulk Density--

Bulk densities were measured on all pretreatment and posttreatment samples from the demonstration. Some other posttreatment values were provided by GE (all on samples prepared by LE for GE) from the first laboratory studies reported by LE, and from the screening tests performed by the EPA.

For the demonstration, the bulk density increase with treatment was quite satisfactory. The average density gain was 21%, changing from 1.55 g/mL (96.7 lb/ft^3) to 1.88 g/mL (117.3 lb/ft^3) for a 32% increase (HWT-20 plus water) in mass. The results of the 3 treated-soil samples provided by GE and measured by EPA during the screening tests were comparable to the samples from the field, and averaged 1.83 g/mL (114.2 lb/ft^3). The earlier laboratory formulations -- with additive dosage rates of 0.10 to 0.25 lb HWT-20/lb soil -- ranged from 1.48 mg/L (92.3 lb/ft^3) to 1.86 g/mL (116.0 lb/ft^3). These latter samples had a moisture content ranging from 2.8 wt% to 13.6 wt%, with the lowest bulk-density values at the highest moisture content. Both groups of test specimens were lower in moisture content than the posttreatment field samples. For the samples described above, untreated-soil bulk densities were not performed. Therefore, it is concluded that a significant bulk-density increase on soil treatment; about 20% is likely at an additive dosage of 0.17 lb/lb of dry soil; and a small but significant volume increase occurs.

Based on all the physical test results performed on IWT treated-soil samples, it would be expected that a potential for long-term integrity of the treated soil exists if the problem for freeze/thaw degradation is overcome.

Microstructural Results

Optical microscopy, scanning electron microscopy, and X-ray diffraction analyses were performed on untreated- and treated-soil samples during the SITE demonstration. These methods are commonly used techniques for understanding the mechanism of structural degradation of soil, cement, and soil-cement mixtures, both with and without the addition of inorganic and organic compounds. Relatively few studies exist of the microstructure of complex waste/soil mixtures such as those resulting from stabilization/solidification procedures. Thus, interpretation of microstructural observations may in some cases be difficult. However, valid information can be obtained on the potential durability of the solidified mass. These observations complement the weathering test results, which are short-term measures of solidified mass integrity, and UCS test results, which are an indirect indication of durability. The microstructural studies provide information on the potentials for structural changes over the long-term, although quantitative predictions on durability are not possible.

The results show that the solidified material has a potential for long-term durability. The solidified

mass is dense, homogeneous and of low porosity. Compositional variations in the vertical and horizontal direction, based on the consistency of the mineral structure from sample to sample, were absent. Thus, it appears that mixing by the Geo-Con DSM equipment was satisfactory. It would seem that the low porosity should reduce the susceptibility to damage from wet/dry and particularly freeze/thaw cycles, by reducing the quantity of water in the pores of the solid (water in the pores would freeze and may cause fracture). However, the test specimen degradation occurring in the freeze/thaw cycling tests appears to conflict with the expected performance of low porosity solids with high strength.

Operations

For this SITE technology, IWT was the provider of the chemical additive, and Geo-Con performed the remedial operations. Geo-Con was responsible for the slurry preparation, flow control of additive and water, and soil injection and mixing. As indicated in Appendix B on Vendor Claims, Geo-Con has substantial experience in shallow- and deep-soil-mixing for contaminated soils, lagoon closures and structural reinforcement.

Equipment operations during the demonstration were satisfactory. Some minor operating problems, readily fixable, were encountered, as described in the Demonstration Report [12]. These minor difficulties included: deviations in the location of the auger from the designated point; a major water leak in the auger drill head, which eliminated the supplemental water for the last 21 soil columns; and inability to maintain automatic feed control of the HWT-20 and water to the auger.

Geo-Con has considerable experience in many types of soil improvement operations. They have constructed more than 400 slurry cut-off walls and performed work on soil capping, lagoon and landfilling closures, soil and sludge stabilization and foundation strengthening. In addition, the technology concept is used by others in the U.S. and has been extensively used in Japan for about twenty years.

Overall, the conclusion is that Geo-Con provides a technology that has proven to be technically sound in most types of soils and should be considered as a valid option where in situ stabilization/solidification or solidification technologies are deemed desirable.

Summary of Performance

Stabilization/solidification technologies generally reduce contaminant mobility, particularly for toxic metals, and increase volume. These techniques nearly always leave some uncertainty about long-term effectiveness, because laboratory tests can neither fully duplicate field conditions over long periods of time, nor establish what actually happens to the contaminants during treatment [15,16]. This is true for the IWT/Geo-Con in situ technology also.

It can be concluded that the overall physical properties of low-concentration-organics soil treated by the IWT in situ process are satisfactory. However, some potential for durability difficulties under freeze/thaw conditions exists. Although IWT claims to be able to process wastes that are high in organics, physical test data that might indicate the potential for long-term durability do not exist. However, IWT claims that chemical bonding is the key aspect of its technology, and its research and additive development is based on this approach; success in this effort will reduce contaminant mobility even if structural integrity of the solidified mass cannot be maintained.

The only field experience of IWT is at the GE site in Hialeah, Fla. For the SITE demonstration, the ability of the HWT-20 additive to immobilize PCBs is not conclusive. However, IWT's laboratory studies indicate that PCBs probably can be immobilized. For the immobilization of volatile and semi-volatile organics and heavy metals, insufficient data exists from the demonstration to draw any conclusions. However, it is possible that the HWT additives provided by IWT are able to immobilize some organics and metals, based on some IWT laboratory results and the fact that some treated organophilic clays [6] with similarities to the HWT family of additives are known to bond to organics and metals.

The Geo-Con deep-soil-mixing equipment worked well at the Hialeah site. Along with their other experience in related work Geo-Con offers a technology that should be considered as a valid option for in situ stabilization/ solidification applications.

Environmental Regulations Pertinent to In Situ Stabilization/Solidification

This section discusses selected EPA guidance concerning federal environmental regulations that may pertain to the use of in situ stabilization/solidification of PCBs and hazardous waste at CERCLA sites. Most of the discussion pertains to any in situ treatment technique. It is beyond the scope of this document to provide a comprehensive description of all regulations that may pertain to the implementation of these technologies. More information on regulations pertaining to CERCLA actions is available in the CERCLA Compliance with Other Laws Manual [17] and the series Superfund Land Disposal Restriction (LDR) Guides [18-23]. Also, although the discussion

focuses on CERCLA activities, it should be helpful to those contemplating the use of this technology for other remedial activities, such as those under RCRA corrective action or RCRA closure.

In Situ vs Staged Treatment

The term "in situ" is a Latin term meaning "in a natural or original position." The term "in place" is often used interchangeably with "in situ." In situ treatment describes treatment of waste that has not been excavated. In practice, treatment may not be feasible or cost-effective unless the waste is first excavated, moved, or consolidated, prior to redeposition in a location specifically designed for treatment. Although technically this "staged" treatment is not treatment in place, the same techniques could be used, such as the application of stabilization/solidification agents using an auger.

Staged treatment may trigger regulatory requirements additional to those that apply to treatment of waste that has not been excavated. For this reason, the discussion that follows distinguishes between in situ treatment and staged treatment. For the purpose of this discussion, in situ treatment refers only to the treatment of waste in place, without prior excavation. Staged treatment is the application of in situ techniques to waste that first has been excavated.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for federal authority to respond to releases of hazardous substances to air, water, and land. CERCLA authorized EPA to revise the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) to include responses to hazardous substance releases. The NCP defines methods and criteria for determining the appropriate extent of removal, remedial, and other measures. The latest revisions to the NCP, which reflect SARA, will be promulgated in early 1990. Specific techniques mentioned in the NCP for remedial action at hazardous waste sites include solidification technology for handling contaminated soil, sediment, and waste.

Section 121 (Cleanup Standards) of SARA requires that remedies be protective of human health and the environment and be cost-effective. SARA states a preference for remedies that are highly reliable; provide long-term protection; and employ treatment that permanently and significantly reduces the volume, toxicity, or mobility of hazardous waste.

Lastly, section 121 requires compliance with Federal and State applicable and relevant and appropriate requirements (ARARs), and provides six conditions under which the ARARs may be waived. The proposed NCP defines applicable requirements as those standards, requirements, criteria, or limitations promulgated under Federal or State law for which the jurisdictional prerequisites fully address the circumstances at the site or the proposed remedial activity. Relevant and appropriate requirements are those that, while not "applicable," address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well-suited to the site.

The discussion that follows first reviews regulatory requirements that may be applicable or relevant and appropriate to in situ or staged stabilization/solidification at a CERCLA site. The guidance on how to determine whether such requirements are ARARs follows the discussion of each set of regulatory requirements.

Resource Conservation and Recovery Act (RCRA), as Amended by the Hazardous and Solid Waste Amendments (HSWA) of 1984

Some of the regulations promulgated under RCRA have potential application to in situ and staged stabilization/solidification at CERCLA sites. RCRA regulations define hazardous wastes, and regulate their transport, treatment, storage, and disposal. Examples of RCRA requirements that may be ARARs for CERCLA activities include regulations for treatment in a tank, performance of incinerators, closure of landfills and surface impoundments, and treatment standards for land disposal (the LDRs).

Definition of Treatment--

Under RCRA section 260.10 treatment is defined as:

> ...any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or so as to render such waste non-hazardous, or less hazardous; safer to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume.

Therefore, stabilization/solidification of hazardous waste is considered treatment under RCRA because it changes the chemical and/or physical characteristics of the waste in order to render it nonhazardous or less hazardous, or easier to manage.

The requirements for treatment of hazardous waste fall into two general categories: treatment in a unit

or treatment prior to land disposal. Most requirements for treatment in a unit are unit-specific design and operating standards. Treatment is regulated in the following RCRA-defined units: tanks, surface impoundments, waste piles, landfills, land treatment units, incinerators, and thermal treatment units. In addition to design and operating standards, requirements for incinerators include a performance standard of 99.99 percent destruction and removal efficiency (DRE) (99.9999 percent DRE for dioxins), in the stack gas emissions.

The requirements for treatment prior to land disposal, or the land disposal restrictions, are concentrations of a contaminant in the waste or waste leachate that must be achieved in order to land dispose the waste. The LDRs are discussed in more detail in a later section.

RCRA and In Situ Treatment--

If in situ treatment is used to treat hazardous waste in a RCRA-regulated unit (for instance, a surface impoundment), unit-specific standards would be pertinent. However, in many cases in situ treatment will be used as part of a RCRA Corrective Action or CERCLA cleanup to treat wastes that have breached any unit boundaries that may have existed, and unit-specific standards would not apply.

In these cases, because wastes treated in situ are likely to remain in place over the long term, in situ treatment is usually governed by site-specific cleanup standards, which are often risk based. Cleanup standards for in situ stabilization/solidification may take the form of permissible levels of certain hazardous constituents in the leachate generated from a standard test, such as the TCLP or EP Toxicity tests. Cleanup standards may also be expressed as concentrations of hazardous constituents in the treated waste, rather than in the leachate. Because most stabilization/solidification agents do not destroy contaminants, but rather make them less available to the environment, this technology may have difficulty meeting a cleanup goal based on an analysis of total waste composition.

If soil and debris are being treated, and the LDRs are applicable, guidance for alternative treatability variance levels and technologies may apply. Immobilization is specified for inorganic contaminants, and standards are expressed as ranges of percent reductions in TCLP leachate values. The ranges vary, but all fall between 90 and 99.9 percent. Specific variance levels for soil and debris are given in OSWER Directive 9347.3-06FS [23].

Since hazardous waste treated in situ will be left in place, provisions regulating closure and post-closure of disposal facilities for hazardous waste may apply. Disposal or landfill closure requires capping and post-closure care, including groundwater monitoring, for at least 30 years. "Clean" closure of a RCRA unit requires removal and decontamination that would allow the site to remain without care or supervision after closure. Hybrid closure combines elements of landfill closure and clean closure. At this time, draft guidance defining performance standards for clean closure are health-based standards for constituent concentrations determined by total waste analysis, not leachate concentrations.

It is important to note that many in situ treatment methods include treatment steps aboveground, such as treatment of volatile organic contaminants removed from the ground via in situ vacuum extraction. Above-ground treatment steps would be regulated by unit-specific standards.

RCRA and Staged Treatment--

If in situ treatment techniques are used to treat waste that has been excavated and staged, RCRA requirements, in addition to those described above, may apply. The potential requirements would pertain to storing and redisposing of the waste, and include land disposal restrictions and standards for construction and managing land disposal units. Under certain conditions, however, such standards would not apply during a CERCLA cleanup or RCRA corrective action. Applicability of RCRA requirements to CERCLA activities is discussed in a later section.

Land Disposal Restrictions--

The RCRA land disposal restrictions (LDRs) are potential ARARs at many CERCLA sites. The RCRA LDRs prohibit, with certain exceptions, the land disposal of hazardous wastes, unless the wastes are first treated to standards established by EPA in RCRA section 3004(d). EPA has promulgated regulations for compliance with the LDRs in 40 CFR Part 268. These regulations specify the treatment standards to which wastes that are subject to the restrictions ("restricted waste") must be treated before being land disposed. The standards are based on what can be achieved using best demonstrated available technology (BDAT). BDAT standards are typically expressed as concentrations of waste constituents that may remain after the waste has been treated, but in some cases are expressed as a specific technology.

If the LDRs apply to a CERCLA response, there are several compliance alternatives: (1) comply with the LDR that is in effect, (2) comply with the LDRs by choosing one of the LDR compliance alternatives (e.g., Treatability Variance, No Migration Petition), or (3) invoke an ARAR waiver (available only for on-site actions). As discussed previously, alternative treatability variance levels and technologies have

been established for CERCLA soil and debris waste that are restricted from land disposal under the LDRs.

Applicability of RCRA Requirements to CERCLA Cleanups--

The CERCLA Compliance with other Laws Manual provides guidance on how to determine which of RCRA requirements are applicable to CERCLA actions. In general, RCRA requirements are applicable to a waste at a CERCLA site when two conditions are satisfied: (1) the waste is a RCRA hazardous waste, and (2) the waste is treated, stored, or disposed of after the RCRA requirement is effective. In general, RCRA is applicable to wastes that were disposed after the effective date of the RCRA Subtitle C requirements under consideration (generally November 19, 1980), or to treatment, storage, or disposal of hazardous waste that had been excavated at a CERCLA site.

Placement--

If "placement" has not occurred, the RCRA disposal requirements are not applicable. EPA uses the concept of "areas of contamination" (AOCs) to assist in defining when "placement" does and does not occur for CERCLA actions involving on-site disposal of wastes. An AOC is delineated by the areal extent of contiguous contamination. For on-site disposal, placement occurs when wastes are moved from one AOC into another AOC. Placement does not occur when wastes are left in place, or moved within a single AOC.

CERCLA Substances vs RCRA Hazardous Wastes--

Not all wastes or substances at CERCLA sites are RCRA hazardous wastes. Based on the information gathered during a CERCLA site investigation, it is determined whether the industrial source or physical/chemical properties of the wastes present at the site demonstrate that the CERCLA waste is a RCRA hazardous waste. For RCRA regulations to be potentially applicable, there should be affirmative evidence (e.g., manifests, records, knowledge of process) demonstrating that the CERCLA waste is a RCRA hazardous waste. If such evidence does not exist, the RCRA regulations are not applicable, but may be relevant and appropriate if the waste is sufficiently similar to a RCRA waste listed from a specific industry or process.

To determine whether a CERCLA waste is a RCRA characteristic waste, site managers may test the waste or use their knowledge of the properties of the waste. To determine if a waste is a listed waste, sampling alone will not be sufficient. The RCRA listing descriptions will generally require that the site manager know the source of the waste or its prior use.

Applicability of LDRs--

OSWER guidance [22] stipulates that for the LDRs to be applicable, the CERCLA response action must constitute placement of restricted RCRA hazardous waste. Placement does not occur, and the LDRs are not applicable if (1) wastes are treated in situ, or (2) wastes are excavated, stored, and redeposited, all within a single AOC, prior to treatment.

The LDRs do apply if excavated waste from an AOC is placed in a separate unit, such as an incinerator or tank that is within the AOC, and then treatment residuals are redeposited into the same AOC. Therefore, if excavated waste is pretreated (e.g., neutralized) prior to redeposition, the LDRs may be applicable. The extent of waste preprocessing that triggers the LDRs is not well-defined at this time.

Conclusion--

Because in situ treatment does not involve excavation or placement of the waste to be treated, it appears that RCRA requirements would be applicable only if the waste to be treated in situ was found to be a RCRA hazardous waste, and the hazardous waste was disposed after the effective date of the RCRA requirements. In these limited cases, although stabilization/solidification is considered treatment under RCRA, most RCRA standards are unit-specific design and operating standards, and do not directly pertain to in situ treatment. The RCRA requirements that are most likely to be ARARs for in situ treatment of hazardous waste are related to the long-term management of the area treated, such as requirements governing closure and post-closure. In most cases, in situ treatment in general will be subject to site-specific cleanup standards.

If wastes are staged prior to solidification/stabilization treatment, RCRA requirements would apply only if (1) the wastes were RCRA hazardous wastes, and (2) the wastes were moved outside the AOC for storage or redisposal. In these cases, additional applicable requirements may include design and operating standards for the land-based unit, as well as the LDRs.

Toxic Substances Control Act (TSCA)

The disposal of PCBs and PCB-contaminated materials, at concentrations of 50 ppm and greater, and wastes resulting from uncontrolled discharges of such materials, are regulated under the provisions of the Toxic Substances Control Act of 1976. Materials containing PCBs at any concentration also may be regulated under RCRA if mixed with RCRA waste. The TSCA regulations, which are found in 40 CFR 761.60, address disposal requirements in relation to

the concentration of the PCBs in the waste. PCBs in concentrations greater than 500 ppm must be disposed by incineration. Wastes containing PCBs in concentrations of 50 to 500 ppm may be disposed of either by landfilling, incineration, or an approved, nonthermal alternative. These requirements are potentially applicable to any waste containing PCBs, even if other contaminants are present.

Several states and local governments may also have their own PCB requirements. For instance, at the Hialeah site, Dade County is requiring GE to treat soils that contain PCB concentrations of 1.0 ppm and above.

TSCA Disposal Requirements for PCBs--

In section 761.3, the TSCA regulations define "disposal" to include "any actions relating to destroying, degrading, [or] decontaminating...PCBs or PCB Items." Incinerators include rotary kilns, liquid injection incinerators, cement kilns, and high temperature boilers. In addition to approved incinerators or other thermal devices, under the authority of section 761.60(e), EPA may approve non-thermal PCB disposal processes of "destroying" PCBs with the same effectiveness as an approved high-temperature incinerator. EPA guidance [24] indicates that an equivalent level of performance for an alternate method of treatment of PCB-contaminated material is demonstrated if it reduces the level of PCBs to less than 2 ppm measured in the treated residual. PCB wastes treated to this level by an approved process are no longer subject to the TSCA requirements. Aqueous streams must contain less than 3 ppb PCBs. Releases to air must be less than 10 µg of PCBs per cubic meter.

TSCA disposal requirements do not generally apply to PCB wastes disposed in disposal sites prior to February 17, 1978, the effective date of the PCB disposal regulations. The TSCA regulations do not apply to the PCBs at the Hialeah site because disposal occurred prior to the February 17, 1978 and because the PCBs are not being removed, but instead being treated in situ, without excavation. However, if PCB waste disposed prior to the effective date of the regulations is excavated, the waste must be disposed in accordance with the PCB disposal regulations.

TSCA Disposal Requirements and Stabilization/Solidification--

Under the disposal requirements, bulk liquid waste containing between 50 and 500 ppm of PCBs must be pretreated and/or stabilized to eliminate the presence of free liquids prior to final disposal in a TSCA-approved chemical landfill. To date, no stabilization/solidification process has been approved as an alternative disposal method to incineration. There are not currently any TSCA permitting standards in place to guide the review of this technology, in view of the difficulty in comparing stabilization/solidification of PCBs with high-temperature incineration. Consequently, Superfund evaluates stabilization/solidification in terms of employing the appropriate long-term management controls consistent with chemical waste TSCA landfill requirements.

Applicability of TSCA Requirements to CERCLA Cleanups--

The Superfund PCB Guidance is due to be published in the spring of 1990. This guidance will clarify when TSCA requirements are ARARs for CERCLA activities. In general, TSCA disposal requirements for PCBs would be applicable to CERCLA activities in two instances. If PCBs were disposed after February 17, 1978, the effective date of the requirements, TSCA disposal requirements would be applicable to the waste, even if it is treated in situ. Excavation of the PCB material for treatment or disposal (such as staged treatment) would also trigger TSCA requirements, regardless of when the waste was originally disposed. Lastly, if TSCA requirements are applicable, it may be difficult to demonstrate compliance with the use of stabilization/solidification alone, without subsequent disposal in a chemical landfill.

As with other hazardous substances, cleanup levels for PCBs are generally established on a site-by-site basis, considering local, state, and federal requirements. The upcoming Superfund PCB Guidance will also provide guidelines on starting point cleanup levels. The PCB Spill Cleanup Policy (40CFR 761.120 through 761.139) gives cleanup guidelines for most spills of PCBs greater than 50 ppm occurring after May 4, 1987. This policy gives cleanup guidelines of 10 to 50 ppm for PCBs in soil, depending on the location of the spill. The PCB Spill Cleanup Policy is to be considered in determining PCB cleanup levels at Superfund sites.

Waste Characteristics and Their Impact on Performance of the Technology

Stabilization/solidification processes involve the addition of agents that are intended to mechanically or chemically bind hazardous constituents to prevent their release into the environment. These processes usually increase the strength and decrease the permeability of the solidified mass. In general, the stronger, more impermeable and durable a treated waste, the more effectively it will contain hazardous constituents. If the material does not fragment, create dust, or increase the surface area available for leaching, losses will be minimized. Stabilization/solidification processes are potentially effective for some types of organics for both soils and sludges, and have been proven effective for various inorganic

wastes, such as metals, asbestos and radioactive materials.

The IWT/Geo-Con process used in Hialeah, Fla. is a cement-based process, where the typical design concept is to solidify and immobilize waste contaminants. The principal differences between this process and other cement-based ones are that the proprietary additive is applied in situ and that chemical bonding of the additive to contaminants may occur, which would contribute to toxic immobilization. The Geo-Con/DSM equipment has a wide range of applicability. It can be used in most soils, with a wide range of physical characteristics, to depths in excess of 100 ft.

The IWT process is claimed to be applicable for treatment of soils, sludges, solids and liquids containing a wide range of organic and inorganic toxic compounds. IWT prefers to treat materials that contain less than 25 wt% organics, except for refinery wastes. For high organic wastes, larger dosages of additive would probably be required. IWT's only field experience is at the Hialeah, Fla. site, where the organic content of the soil was very low (<1.6 wt%). Its experience with high-organic-content wastes consists primarily of laboratory tests where some posttreatment leach tests and chemical bonding studies were performed, but physical property studies were not performed. Thus, very limited proven experience with a variety of soils exists, which would necessitate treatability studies to confirm anticipated performance for each potential waste, especially those high in organics content.

Although an HWT-20 admix was selected for use at the Hialeah site for the treatment of PCB-contaminated soils, other formulations exist to treat other contaminants. IWT is continuing to develop new formulations that will improve chemical bonding and even degrade various organic toxins to less toxic compounds. Thus, the IWT additive may be able to treat a wide variety of solid and liquid wastes, both organic and inorganic.

The Geo-Con/DSM equipment can operate in virtually all types of soils. Clays, oily sands and cohesive soils may reduce auger penetration rate. They may also limit the depth of operation to about 60 ft (due to the excessive torque required). This depth should be well below any soil contamination at most locations. In a non-cohesive soil, such as a sandy loam, penetration rates up to 6 ft/min have been used by Geo-Con for grout injection. In cohesive soils, the rate would probably be below 3 ft/min. The primary limitations on using the equipment (which may be circumvented by excavation at shallow depths) and special injection procedures at greater depths, are caused by large rocks (>10 in.), lumber, drums, etc. Another factor that could impact operation is that a level surface is needed for the DSM equipment.

A small enclosed site (smaller than the Hialeah site) may also provide difficulties of site access for the auger injection system. To ease this difficulty, the additive preparation system can be erected remote to the DSM equipment. This may also allow for its operation in a clean zone. However, the larger the distance between the two parts of the system, the more likely that slurry plugging of the transfer lines could occur, the more energy would be consumed and the more difficult would be the communications to coordinate activities.

Subfreezing temperatures may impact the process in two ways:

- IWT - The cement hydration reactions are usually affected by temperatures below 40°F, causing a poor quality product. This may be overcome in some circumstances by special cements or by preheating the additive stream to 40 to 50°F.

- Geo-Con - Low temperatures may cause slurry freezing in the pipe lines between preparation and the auger injection nozzles; operations have been successful down to a temperature of 10°F. In very severe cold -- well below 0°F -- inability to penetrate the frozen earth may cause operational stoppage.

Typically, cement-based stabilization/solidification systems have the following potential limitations to their effective use:

- Organics content above 45 wt%. This limitation may not apply to the IWT additives because they contain organophilic clays that may help in the immobilization reactions.

- Wastes with less than 15 wt% solids.

- Excessive quantities of fine soil particles (<74 μm) and excessive large particles (>0.25 in.)

- Various chemicals may retard setting or interfere with cement bonding, such as: phenols; halides; cyanides; soluble salts of manganese, tin, zinc, copper, and lead; arsenates; borates; and some others.

- Sulfates could cause swelling and spalling of the cement.

- VOCs may be driven off by the heat of the hydration for the cement reactions.

Acidity of the soil or sludge should not present problems, as cement is highly alkaline. In addition, lime could be added to provide additional neutralization potential. The ability of the HWT additives to overcome the above listed potential problems has not been addressed by the developer.

Material Handling Required by the Demonstrated Technology

A successfully treated product from the IWT/Geo-Con in situ stabilization/solidification system depends on proper weight, flow calibrations, and ratios of the admixes. Component feed variations, such as "slugs" of oil and grease in an otherwise uniform soil, may present some difficulties. In order to overcome this disadvantage, if this is a frequent occurrence, the process is capable of using higher-than-required admix ratios. However, this procedure is less cost effective. The primary advantage of in situ operation is that excavation and transporting of the contaminated soil is not necessary.

For in situ treatment, heavy equipment is required to properly inject and mix the additives with the waste. Both in situ and waste-excavated systems for above-ground treatment require air monitoring equipment to track organic and dust exposures during injection, excavation, transport and feed to the system. Contaminated water, whether surface or groundwater, can be used in the process as the water additive.

The materials handling associated with the Geo-Con DSM consists of a slurry preparation system, usually remote from the injection auger and in a non-contaminated area. Thus, a slurry has to be pumped a considerable and variable distance to reach the auger. Since a 57-wt% solids slurry is being handled, the design must prevent solids settling to avoid line plugging. The front-end of the slurry preparation area has less potential for difficulties, and it consists of feeding a storage silo by an air-conveying system from the supply truck. From the silo, a calibrated rotary valve is used to feed the slurry preparation system. This slurry preparation is batch operated, but could be designed for continuous operation also. To confirm that the correct amount of water and additive was added to the slurry tank, the density of the slurry is measured onsite by a mud balance.

Personnel Issues

Eleven people are required for the 1-auger and 13 for the 4-auger Geo-Con/DSM units. This includes operators, supervisors, health and safety officer, plus office personnel and a sampling technician. This is based on a one-shift-per-day operation. These people must pass appropriate physical exams and have completed an approved 40-hour hazardous-materials training course.

Personnel are subjected to the standard OSHA requirements for operating moving equipment and would be required to wear the proper personal protective equipment dictated by the specific site conditions and contaminants. Personnel have minimal contact with the waste, as all streams are remotely handled, except during decontamination and maintenance. This is also true for many remediation processes.

Procedures for Evaluating Stabilization/Solidification

Critical parameters in stabilization/solidification include the selection and quantity of additive, plus mixing and curing conditions [25]. These parameters depend on the chemical and physical characteristics of the waste. Bench-scale treatability tests should be conducted to select the proper additives, quantities and curing times. Therefore, chemical analyses of the waste should be performed using EPA accepted procedures [26], to define the type and quantity of contaminants, along with leach tests to obtain untreated leachate concentrations. After waste treatment, the leach tests should be repeated, as well as unconfined compressive strength tests. This would be the minimum of tests performed. If time and money are available, moisture content, bulk density, and weathering tests should be added.

For evaluating the IWT/Geo-Con process, a more complete sampling program was defined in the Demonstration Plan. The samples taken and analytical procedures used were selected based on the information required to provide answers to the technology evaluation criteria. The two important technical criteria to evaluate any stabilization/solidification technology are: immobilization of the contaminants, and durability of the solidified mass. Tests were drawn from various related fields and applied to the hazardous waste to obtain the answers. Other tests, such as acid neutralization and specific gravity, also could have been performed as part of the evaluation. The most important factors in evaluating contaminant mobility are:

- To relate pretreatment to posttreatment results
- To measure contaminant concentration in the waste for the samples being used in leaching tests

Therefore, for both pretreatment and posttreatment samples, soil samples were analyzed for PCBs, VOCs, and heavy metals before samples of the same material were leached. The TCLP test is the most

widely accepted procedure and is the basis for proposed regulatory levels for organics and heavy metals. It is the most important test in the program for evaluating contaminant mobility. Two additional leach tests, MCC-1P and ANS 16.1, also were used on selected posttreatment samples; they attempt to evaluate leaching from a solidified mass. MCC-1P simulates a quasi-static groundwater regime in contact with the waste where saturation concentrations may be approached, and ANS 16.1 simulates a more-rapidly moving groundwater where saturation is not reached. These tests were drawn from the nuclear industry and are relatively expensive to perform. They also use different leachate-to-solid ratios compared to the TCLP test and to each other, so only a qualitative relationship between test results is valid.

Following the TCLP test, the next most important test is permeability, which is a measure of flow of water through the solid. Since water is the leaching agent, only water coming in contact with the contaminants can leach the toxins out. A constant-head permeability test -- such as ASTM D-2434-68 -- can be used for untreated soils where permeabilities are relatively high, more than 10^{-4} cm/s. For the treated soils -- where permeabilities may range from 10^{-6} to 10^{-8} cm/s -- the falling head permeability test is used. This is described in Test Methods for Solidified Waste Characterization (TMSWC) [27].

Once the contaminant is immobilized, the main concern is how long it will remain that way. Therefore, tests were performed to provide information on potential durability of the treated soil. In addition, testing must include a long-term monitoring program -- for this SITE project a 5-year period -- in which samples are collected from the treated soil that has been exposed to the weather. The most prominent test is UCS, which provides a measure of the quality of the solidified mass. It is a test commonly used by the cement industry and is relatively inexpensive.

Wet/dry and freeze/thaw 12-cycle tests provide additional information on degradation of the solidified material. The tests used are described in TMSWC and are very similar to the ones used by ASTM. These tests provide an indication as to whether the solidified material, when saturated or near saturation (such as occurs with a high water table), will disintegrate over the first few weathering cycles, which may take place within the first year. The tests cannot be used to predict the life of the solidified mass in terms of decades or centuries.

The final group of tests, which can be performed and interpreted at only a few laboratories, go under the general heading of microstructural analyses. Both treated-soil samples and a few untreated ones are analyzed by the following methods:

- X-ray diffraction (XRD) - This defines crystalline structure, which can indicate changes from the normally expected structure.
- Microscopy - both optical and scanning electron microscopy (SEM). These techniques characterize crystal appearance, porosity, fractures and the presence of unaltered waste forms. From these observations, mixing efficiency can sometimes be estimated.
- Energy-dispersive X-ray spectrometry - This can determine elemental analysis of crystal structures and hence composition.

These tests are proven analytic methods for understanding the mechanism of structural degradation in materials similar to those of the demonstration. The literature is replete with examples of SEM and XRD analyses of soil, cement, soil-cement mixtures, and each of these mixed with various inorganics and organic compounds. However, there have been relatively few studies of the microstructure of complex waste/soil mixtures, such as those resulting from a stabilization/solidification procedure. Consequently, in some cases, interpretation of the microstructural observations may be difficult.

These microstructural data provide information on the potential for long-term durability of the solid. They cannot quantitatively predict the life of the solid mass or provide a direct relationship to results from the other tests described above. In the future, if a body of data is developed from long-term monitoring programs, the predictability of and interrelationships among these procedures will improve.

Another test of importance, but one not directly related to the two technology evaluation criteria (immobilization and durability), is the inexpensive test of measuring bulk density. In all solidification processes, pozzolans and special additives, along with water in many cases, are added to the waste. These could result in major waste or soil volume changes, which may affect the remediation procedures. Bulk density measurements of the soil before and after treatment, along with a material balance, will provide a method of calculating volume change during the remediation process.

The other physical tests -- moisture, pH and particle size distribution (PSD) -- are typical soil tests and provided background information that could become important if problems occur. Moisture and pH tests are very inexpensive and a PSD is moderately priced.

Section 4
Economic Analysis

Introduction

A primary purpose of this economic analysis is to attempt to estimate costs (not including profits) for a commercial-size remediation. It is assumed for this analysis, which is based on the test at Hialeah, that part of a large Florida site is to be remediated. Many costs are site specific, being affected by such factors as: site geology; type and quantity of contaminants; proximity to the community or to other industrial sites; regulatory requirements; and local costs of labor, utilities and raw materials. The analysis assumes that the remediation occurs in Florida in a spacious, rural setting, and it simplifies and eliminates some potentially expensive site-specific costs.

Due to the short-term nature of the demonstration and the fact that labor, equipment rentals and chemical expenses dominate the remediation costs, the actual costs for Geo-Con and EPA were not used. However, Geo-Con provided information from its quotation to GE and this was used as a basis. Information was provided for a 1-auger machine for the demonstration, and a 4-auger unit that would be used for a larger application, such as the complete remediation of the GE site.

Many actual or potential costs exist that are not part of this estimate.

The major items are as follows:

- At the site a prime contractor performs many functions, including some services not shown, or only partially included in this cost estimate. This includes site preparation, such as building roads, providing access to the treatment area and providing utilities to plant battery limits. Battery limits can be defined as the limits of a space envelope that includes all of the Geo-Con equipment plus support equipment to which utilities and access must be provided.

- The treated waste has a greater volume then the untreated waste. Thus, the treated waste will cause the ground surface to rise, the amount depending on the depth of the treatment operation. The cost of removing excess material to a landfill could be quite substantial and is not included.

Even if the excess is moved to another part of the site, or if it is left in place, land contouring would be required at some expense. Depending on the option required, appreciable variations in these costs may be encountered.

- Permitting, and environmental monitoring of operations for regulatory authorities are not included.

- Operations are assumed to be 5 d/wk and 8 h/d. Any changes in this schedule would change the remediation cost. For example, 24 h/d operation would reduce it, by decreasing the labor and equipment rental costs.

- Treating an oily waste requires an increased additive ratio, possibly 0.25 lb HWT-20/lb dry soil or more, instead of the usual value of 0.15 lb HWT-20/lb dry soil. This would increase operating costs by about $34/ton.

The results are presented in Table 2.

Results of Economic Analysis

The results of the analysis show the approximate cost per ton for the 4-auger application is $111 and for the 1-auger application is $194. Some items mentioned in the previous subsection and discussed in more detail under Basis of Economic Analysis, could increase the cost. Extreme care in defining any ground rules for the economic analysis is required.

The results show that 85% of the costs are for raw materials (HWT-20), equipment rental and labor. IWT estimated the cost of HWT-20 at $380/ton. All costs are site-specific; on the west coast the cost might be 20% greater. Labor costs include 10 people to operate the 4-auger unit, and 8 people for the 1-

Table 2. Estimated Cost (a,b), $/Ton

	4-Auger system	1-Auger system
Site Preparation	--	--
Permitting and Regulatory	--	--
Equipment		
Geo-Con, $ (c)	801,000	77,000
Equipment rental + subcontractors	26.23	67.90
Consumables	6.94	19.29
Contingency (10% of direct costs)	1.18	0.45
Start-Up and Fixed Cost		
Operator training	0.45	0.31
Site mobilization	0.90	0.31
Depreciation (10% of direct costs)	1.18	0.45
Insurance and taxes (10% of direct costs)	1.18	0.45
Labor Costs		
Salaries and living expenses	15.38	45.73
Administration (10% of direct costs)	1.18	0.45
Supplies - Raw Materials		
IWT additive, HWT-20	52.45	52.45
Sodium silicate	0.23	0.23
Supplies - Utilities		
Fuel ($1.00/gal)	0.90	2.16
Electricity ($0.04/kWh)	0.06	0.21
Water ($0.80/1,000 gal)	0.02	0.02
Effluent Treatment	--	--
Residual Transport	--	--
Analytical	1.14	3.28
Facility Modification (10% of direct costs)	1.18	0.45
Demobilization	0.90	0.31
Totals	111.50	194.45

Notes
(a) This does not include profits of the contractors.
(b) The American Association of Cost Engineers defines 3 types of estimates: order of magnitude, budgetary, and definitive. This estimate would most closely fit an order-of-magnitude estimate, with an accuracy of +50 to -30%. However, this being a new technology, the range on the potential accuracy may be significantly wider.
(c) Not used directly, but used for the estimate of other costs.

auger machine. In addition, 3 people are assumed for purchasing, administration, and sampling.

The largest cost savings in remediating the site results from using the 4-auger DSM unit, which would reduce operating time, thus saving both labor costs and equipment rentals. The next-largest cost factor is the additive, which is being used at a rate of 15 lb/100 lb of dry waste. This value is near the minimum, and could increase significantly for hard-to-treat wastes, such as those high in oil and grease.

Basis of Economic Analysis

The costs analysis is prepared by breaking the costs into 12 groupings. These will be described in details as they apply to the IWT/Geo-Con in situ stabilization/solidification process. The categories, some of which do not have costs associated with them for this technology are as follows:

- Site preparation costs -- including site design and layout, surveys and site investigations, legal searches, access rights and roads, preparations for support facilities, decontamination facilities, utility connections and auxiliary buildings.

- Permitting and regulatory costs -- including permit, system monitoring requirements, and development of monitoring and analytical protocols and procedures.

- Equipment costs. Broken out by subsystems, including all major equipment items -- process equipment, materials handling equipment and residual handling equipment. Also includes descriptions of the equipment specifications (i.e., throughput and utilization rate).

- Startup and fixed costs. Broken out by categories, including mobilization, shakedown, testing, working capital, depreciation, taxes, and initiation of environmental monitoring programs.

- Labor costs. Including supervisory and administrative staff, professional and technical

staff, maintenance personnel, and clerical support.

- Raw materials. HWT-20 and sodium silicate. This is the largest of the 12 cost categories for the IWT/Geo-Con technology, and any design optimizations based on treatability studies or direct field experience could have a large impact on the bottom line.
- Supplies and consumables. Includes utilities, such as fuel, electricity, and water, and posttreatment of the treated soil and any byproducts.
- Effluent treatment and disposal. Both onsite and offsite facility costs, including wastewater disposal and monitoring activities.
- Residuals and waste shipping, handling, and transport. Including the preparation for shipping and actual waste-disposal charges.
- Analytical. Including laboratory analyses for operations and environmental monitoring.
- Facility modification, repair, and replacement costs. Including design adjustments, facility modifications, scheduled maintenance, and equipment replacement.
- Demobilization. Including shutdown, site cleanup and restoration, permanent storage costs, and site security.

The estimates are based on the following general assumptions:

- The remediation occurs at a large, rural Florida site.
- A total of 38,400 tons of soil, containing 8 wt% moisture, is processed in each of the two cases estimated. This figure assumes that 50,000 ft^2 is treated to a uniform depth of 16 ft, with the soil density the same as the GE site, 96 lb/ft^3.
- Although there was a prime contractor onsite, this cost is not included. The contractor provided certain functions for the IWT/Geo-Con processing unit, such as site preparation.
- Many of the cost estimates were provided by Geo-Con [28].

The twelve cost factors, along with the assumptions utilized for each, are described below.

- Site preparation costs. It is assumed that this work will be performed by the site prime contractor and that there will be no charges to this cleanup. This assumes that roads, site preparation for the Geo-Con DSM machine and its support equipment, and access to the feedstock are provided by others, along with the supply of electricity and water to battery limits. It also assumes that any final contouring of the land will also be performed by the prime contractor.
- Permitting and regulatory costs. It is assumed that this hypothetical Florida site is a Superfund site, so no permits will be required, either federal or state. The need for developing analytical protocols or monitoring records is assumed not to exist. On non-Superfund sites, this activity could be expensive and very time consuming.
- Equipment costs. Based on information provided by Geo-Con, the capital cost for the 1-auger machine is $77,000 (plus some equipment rentals) and $801,000 for the 4-auger machine. Of these total costs, the mixing plant was approximately $50,000 and is the same for both units. Equipment rental costs and subcontract costs were provided by Geo-Con, and (with some adjustments) were $26.23/ton and $67.90/ton for the 4-auger and 1-auger units, respectively. Geo-Con's profit was estimated so that their quotation values could be converted to costs. Additional items -- such as fuel, sodium silicate, water storage, fences, and lighting -- are assumed to be provided by the prime contractor and are not included in these remediation costs.

  The equipment rental and subcontracts are one of the largest operating costs. Rental equipment includes such items as front-end loaders, backhoes for soil excavation and transport, a steam cleaner for decontamination, a pickup truck, a drill rig, a crane and personnel facilities. The subcontracts include such items as trucking, piping and electrical hookup.

  Consumables are also included in this group, and include expendable health and safety clothes, health and safety instrumentation, trailers for office space, sanitary facilities, lights and sampling materials. Geo-Con provided a cost for consumables of $9/$yd^3$ for the 4-auger machine and $25/$yd^3$ for the 1-auger machine.

  Since some additional equipment is required for this hypothetical site compared to the GE site, and Geo-Con's values include profit, the analysis assumed that these dollar values balanced and that Geo-Con's quotation was to be only costs.

A contingency cost, approximately 10% of the direct costs on an annual basis, is allowed for unforeseen or improperly defined costs. This is separate from the previously described design basis uncertainties.

- Startup and fixed costs. The costs included in this group are operator training, initial shakedown of the equipment, equipment depreciation, insurance and taxes. The labor costs and living expenses for mobilization, operator training, and initial shakedown of equipment are estimated from Geo-Con's total labor-cost quotation.

  It is assumed that 5 days of training are required for the Geo-Con operators, supplementary field personnel, the site health and safety officer and the sampling technician. The costs include salaries, overheads and expenses at the rates described below for labor.

  Initial startup includes setup of the Geo-Con equipment and checkout of its operation. One week is allowed for this site mobilization, but travel costs to the Florida site are not included. The installation of any support tankage, pumps, etc., is not assumed as a charge to the remediation. This is probably a modest cost, equivalent to a few dollars per ton, but the design of a system and a budgetary or detailed estimate of it is outside the scope of this economic analysis. For purposes of this estimate, this installation work is assumed to be by the site prime contractor and not charged directly to the IWT/Geo-Con operation.

  The depreciation costs are based on a 10-yr life for all equipment. Costs are based on the write-off of $77,000 worth of equipment for the 1-auger system and $801,000 for the 4-auger system.

  Insurance and taxes are lumped together and are assumed to be 10% of direct costs taken on an annual basis.

- Labor costs. These costs are salaries plus overhead, along with living expenses and some miscellaneous administrative expenses. It is expected that a total of 13 people will be required for the 4-auger unit and 11 people for the 1-auger unit. It is expected that most of the people will be on expenses, except for the 3 support people who are assumed to be local hires.

  Geo-Con indicated they require a total of 10 people for the 4-auger machine and 8 people for the 1-auger unit. It is also assumed that there is 1 office manager at $30/h, 1 secretary at $16/h, and 1 sampling technician at $25/h. These 3 people are assumed to be locally hired and not on an expense account. The costs -- which are provided by Geo-Con and include startup and operating training (after correcting for profit) -- are $13.20/ton of waste for the 4-auger unit and $37.02/ton of waste for the 1-auger unit. All these costs are assumed to include a 10% to 15% contingency that allows for overtime and unexpected expenses. The values shown in Table 2 include the 3 additional people described above.

  An additional labor-related expense item is administrative costs, which include office expenses, such as supplies, telephones, furniture, and reproduction equipment, but not salaries. This cost is assumed to be 10%, on an annual basis, of direct costs.

- Supplies and consumable costs - raw materials. This cost group includes typical variable costs and is the largest expense for the 4-auger unit. The raw materials are the IWT additive, HWT-20, and sodium silicate. The cost for HWT-20 was provided by IWT. The HWT-20 was charged to the project at $380/ton delivered to the Florida location. The HWT-20 was assumed to be used at a rate of 0.15 lb/lb dry soil with the soil at an average moisture content of 8 wt%. The sodium silicate is assumed to be added for the bottom 3 ft at 5% of the rate for the HWT-20. The cost of sodium silicate, based on a verbal quotation from a supplier, is $0.0885/lb.

- Supplies and consumable costs -- utilities. The utilities included are fuel, electricity and water. Also included are byproducts that require treatment or transport to a landfill. The latter item does not apply to this economic analysis, since no byproducts are produced.

  It was estimated that the total fuel consumption for the 4-auger system, for the crane and all the associated vehicles is 200 gal/d, and for the 1-auger system, is 140 gal/d. External electricity is not required for this equipment. The fuel was assumed to cost $1.00/gal. Electricity is assumed to power lights, trailers, etc., at an assumed average daily-rate of 10 kW. The cost of electricity is assumed to be $0.04/kWh.

  Water use is primarily for the process, with 500 gal/d assumed for equipment decontamination and other miscellaneous requirements. Based on a material balance that assumes the untreated soil contains 8% moisture and the treated soil has 18% free moisture plus water

for cement hydration, the water consumption is approximately 14.2 gpm for the large unit and 4.3 gpm for the smaller unit. The cost of water is assumed at $0.80/1,000 gal. There are no byproducts from the IWT process, and soil pretreatment or posttreatment is not necessary.

- Effluent treatment and disposal costs. Since there are no liquid effluent streams associated with this technology, no costs accrue to this category.

- Residual and waste shipping, handling and transport costs. There are no residuals or byproducts associated with the IWT technology. Therefore, there are no expenses associated with this category of potential costs. However, if this changes due to the inability of the site to handle the volume increase produced in the treatment of the wastes, a major new expense for transporting the excesses to an approved landfill would occur.

- Analytical costs. It is assumed that sample sets will be taken daily for the first two weeks of operation. After that, samples will be collected once a week until the cleanup is completed. Both physical and chemical analyses will be run on all samples, with the cost per set approximately $1,200. The cost/ton reported in Table 2 is an overall average value, based on a completed project.

- Facility modification, repair and replacement costs. The costs accrued under this category include maintenance and working capital. Maintenance materials and labor costs are difficult to estimate and cannot be predicted as functions of preliminary design concepts. Therefore, annual maintenance costs are assumed as 10% of capital costs. Working capital costs are assumed to be negligible, as all supplies purchased to have on-hand are assumed to be fully consumed by the project's completion. The cost of using money early in the project is neglected.

- Demobilization costs. It is assumed that all personnel will be onsite for one week for demobilization. This is sufficient time for disassembly of the Geo-Con equipment, decontamination and cleanup. Any additional work required to return the site to pretreatment condition is assumed to be done by the site prime contractor and is not charged to the IWT process.

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Appendix A
Process Description

Description of the Primary Treatment Mechanisms

Solidification and stabilization are treatment processes that are designed to accomplish one or more of the following results [1,2]:

- Improve the handling and physical characteristics of the waste, as in the sorption of free liquids
- Decrease the surface area of the waste mass across which the transfer or loss of contaminants can occur
- Limit the solubility of any hazardous constituents of the waste, e.g., by pH adjustment or sorption
- Change the chemical form of the hazardous constituents to render them innocuous or make them less leachable.

Solidification entails obtaining these results primarily by producing a monolithic block of treated waste with high structural integrity. Stabilization techniques limit the mobility of waste contaminants or detoxify them, whether or not the physical characteristics of the waste are changed or improved. This is accomplished usually through the addition of materials to ensure that the hazardous constituents are maintained in their least mobile or least toxic form [3].

One goal of treating hazardous wastes is removal of the particular waste compound or compounds from the hazardous waste category; this process is called delisting. Delisting of stabilized/solidified waste is possible upon the demonstration to EPA's satisfaction that the component or characteristic for which the waste originally was listed: (1) is no longer present in the treated product; (2) no longer exhibits the characteristics of the original waste; or (3) contains the contaminants exclusively in an immobile form. This determination of the nonhazardous character of the waste product makes possible the less expensive and less rigorous disposal of the wastes in any solid waste landfill.

Treatment Process Flow

In the IWT in situ stabilization/solidification process the contaminated material is mixed with water and a cement-based proprietary additive called HWT-20. The developer (IWT) claims the contaminants bond to the additive, as well as producing a cohesive mass, thus immobilizing the contaminants.

A batch mixing plant prepares and feeds the additives (see Figure A-1). HWT-20 is conveyed from a supply truck by air to a storage silo. A measured amount of water is fed to a mixing tank, and HWT-20 is added at a weight ratio of about 4/3 to water. A positive displacement pump then feeds the slurry to the drill rig. The HWT-20 feed rate is nominally 15 lb dry additive/100 lb dry soil but may be greater for difficult applications, such as oily sludges.

Supplementary water is fed to the drill rig on a ratio basis to the slurry. This ratio varies with soil moisture content. At Hialeah this was based on being above or below the water table. The final soil/HWT-20/water slurry is targeted to contain approximately 1.6 to 1.7 lb water/lb HWT-20.

The control system for the Geo-Con equipment consists of the following:

- Water totalizer for flow to the slurry mix tank
- HWT-20 rotary feeder between the storage silo and mix tank
- Magnetic flow meter for measuring slurry flow to the drill rig
- Flow totalizers for supplementary water
- Instrument package that controls the ratio of slurry feed to the drill rig auger penetration rate and water-to-slurry feed ratio

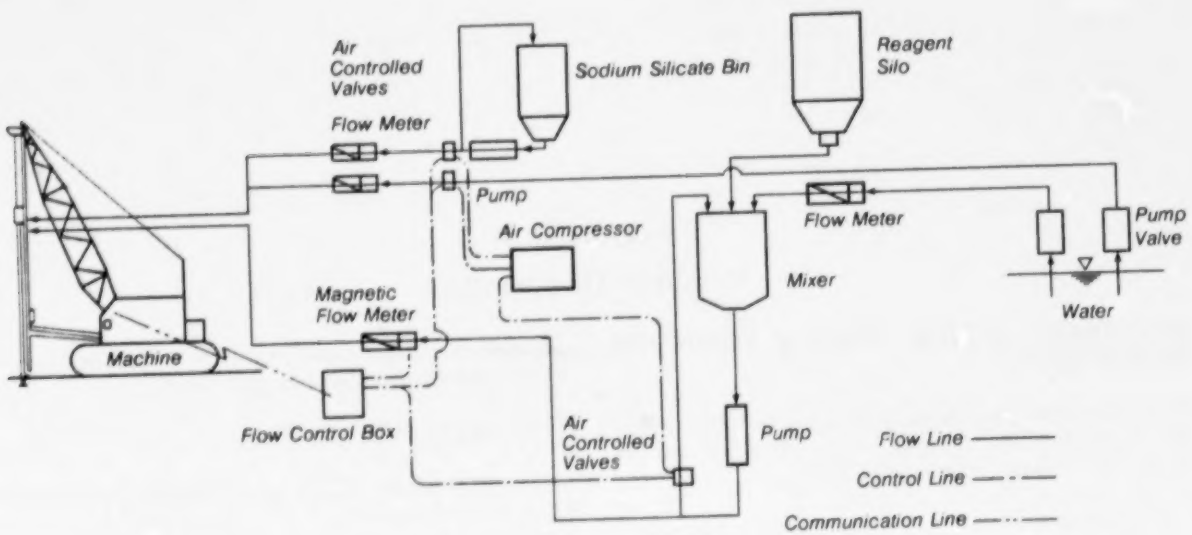

Figure A-1. Batch mixing plant.

The Geo-Con/DSM system of mechanical mixing and injection consists of 1 set of cutting blades and 2 sets of mixing blades attached to a vertical drive auger. The blades rotate at approximately 15 rpm. Two conduits are constructed inside the drive rod and injection ports are provided at the bottom of the shaft, so that the additive slurry and water can be injected into the zone being agitated by the rotating blades. To create a vertical column of treated soil, the blade is advanced to the desired maximum depth of treatment. The HWT-20 additive is injected in slurry form and mixed into the soil and limestone as the blade is rotated during entry into the soil, and is mixed again on withdrawal from the ground. As necessary, additional cycles of injection and mixing are made along the length of the column to provide the required blending. Column positioning is planned so that the columns overlap, and all the ground in the target area is affected (see Figure A-2). The diameter of the treated soil column is approximately 36 in. The drilling pattern consists of alternating primary and secondary strokes. In each sector, all the primary columns are performed before the secondary columns.

The DSM machine tracks into position, and the horizontal and vertical alignments are checked. The elevation measurements are made by using a small tracking wheel attached to a digital tachometer. This fixture is mounted at the top of the auger head and tracks the depth of the drill head. The tachometer output is shown on a digital display. Machine location verification is by use of a stationary laser. The control of the positioning is to about one-tenth of a degree from vertical for the suspended auger.

For large-scale commercial operations, a 4-auger DSM machine would be used. The overlapping column arrangement still exists except that the alternative primary and secondary columns are by groups of four.

Comparison to Existing Treatment Technologies

Comparing the IWT process for in situ stabilization/solidification to other cement-based technologies reveals that unique characteristics exist in the IWT immobilization action of the additive on the contaminants and the equipment used. The proprietary additive is a silicate-based cementitious material, which also includes organophilic clays. These types of clays have been known, with proper treatment, to adsorb organic as well as inorganic material and allow interaction with cement. They also can be tailored by chemical treatment during additive preparation to allow adsorption of different groups of organic compounds. Using these characteristics for hazardous waste immobilization is a new and novel approach. The IWT chemical fixation products can be used for the treatment of both organic and inorganic toxic wastes.

In situ treatment of contaminated soils is also unusual. This approach uses technology that has been used in Japan for two decades to improve soil characteristics. It has been used in Japan, and for the last few years by Geo-Con, Inc., in the U.S. for shoring building foundations, making slurry-retaining walls, filling voids in soil, and for providing soil consolidation and environmental

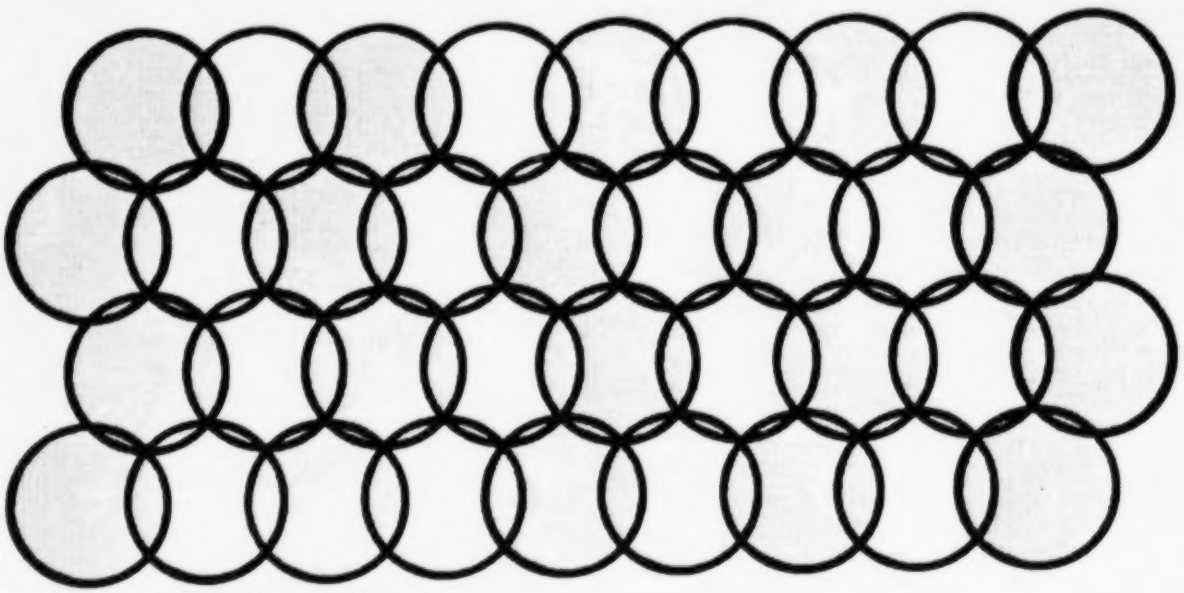

Figure A-2. Overlapping column arrangement.

barriers. Virtually all competing technologies first excavate the soil, treat it, and then return it to the ground. Thus, the major expense of excavating, sizing, and handling the soil is eliminated with use of the IWT/Geo-Con process.

Appendix B

Vendor's Claims for the Technology

The information in the appendix is prepared by IWT and GEO-CON, INC. and provides their claims for their technologies. The reader is cautioned that these claims are those made by the vendors and are not necessarily substantiated by test data. The claims are evaluated against the test data in Section 3 and Appendix C.

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Conceptual Basis of the Advanced Chemical fixation (ACF) Technology

Waste treatment techniques that are composed of Portland cement, fly-ash, cement kiln dust, quick-lime, soil, clay, asphalt, sodium silicate, slag, gypsum, etc., in various combinations for solidification/stabilization (S/S) have been used for a number of years all over the world. Users and suppliers of these technologies have in some cases also used the term chemical fixation (CF) to define various compositions of these materials, possibly with the addition of trace compounds to accentuate their effectiveness with certain waste types. Whatever the terminology used, S/S or CF, particular compositions of these materials are the basis of the proprietary treatment products on the market. Certainly one of the major appeals of this class of treatment technology is the relatively lower cost, if the treatment is sufficiently effective for the waste types to which it is applied. Stabilization/solidification has been viewed by many in the environmental field as a physical or civil engineering process instead of a sophisticated chemical system. Tests for the effectiveness of treatment revolved around certain level of physical changes in the "ante et post" treatment state. "Successful" treatments of some metals, radioactive and nonradioactive, in certain concentrations in sludges, soils, and liquids, as measured by particular light acid and water leach tests, have given additional marketing credence to the notion that this is a viable and effective treatment for a wide range of waste types. Very little in-depth research of the chemistry and physics of S/S and CF was done because "it worked", as determined by certain static and dynamic, deionized water leach tests. Also the use of the term CF with various associated unsubstantiated or stretched logic claims as to a given product or composition's ability to treat a given waste effectively added another level of apparent creditability. In parallel to the use of S/S over the past few years, there has been a somewhat erratic, or wandering, but yet evolving regulatory structure, influenced by an increasingly negative and dubious public opinion of the true effectiveness of S/S and CF and its users. The environmentally active and concerned public elements and to an increasing degree the regulatory authorities saw no true distinction between S/S and CF except marketing hyperbole. In many groups, S/S and CF are viewed as "low tech, no-tech, or pseudo-tech" approaches to waste treatment. Important to solving the effectiveness issue are the questions of what comprises reasonable, realistic, or necessary test procedure of S/S and CF technologies and the "how clean is clean?" standards. The treatment evaluation methods and standards for S/S and CF are a point of contention among the users and marketers of S/S and CF, competing forms of treatment, the regulatory authorities, and the public.

In the midst of this complex scenario we have been doing research into the basic chemistry of chemical fixation of organics and inorganic toxic contaminated soils, sludges, and liquids for the past few years. We believe the necessary reality of S/S, or more appropriately defined CF, involves exceedingly complex chemical mechanisms and phenomena, and this class of technology should be evaluated on such terms as to its true effectiveness. One of the major objectives of this article is to develop a definitional separation between the nature of S/S and CF using the HWT-20 Series (Patent Pending, IWT) compositions as the prototype of a new Advanced Chemical Fixation (ACF) class of treatment technology. In that regard, we will review GC/MS readings of acid leach and solvent extraction tests of cases involving soils contaminated with PCBs and other high content mixtures of organics treated with the International Waste Technologies (IWT), HWT-20 Series Products. A recently discovered problem with high content organic waste treated with a typical S/S mixture using a quick-lime, pozzolan base will be discussed. We have also used infrared adsorption (FTIR) and differential scanning calorimetry (DSC) to give insights into the chemical bonding mechanisms of this particular type of ACF technology with a range of organic compounds in a pure liquid or contaminated soil form. It would be useful at this point to give some background information relative to the chemical design and analytical thinking that went into the HWT-20 ACF prototype. As was implied earlier, we believe that S/S and CF should be based on an accurate paradigm of the chemical process rather than an adsorption/dilution panacea judged effective only by end-state physical characteristics of questionable relevance and validity. Our position is that the extent and strength of the chemical bonding and alteration to innocuous forms within the treated matrix is a truer measure on the short and long term effectiveness of this category or form of treatment.

Chemistry Overview

This HWT ACF technology is based on three sets of interrelated functional chemical groups. There is a matrix cement chemistry, a free radical and ion attack and organophilic linking mechanisms. The underlying concepts have been discussed in some intermediate level of detail in previous papers, so we will summarize this time.

Cement Matrix Chemistry

The objective of the cement chemistry is not primarily end-state physical properties, but the

facilitation of the overall objective of bonding the toxic molecules and ions within a given contaminated material. In line with that point, certain aspects of the cement hydration reaction (CHR) are altered and stretched out in time; the fibrils (sulpho-ferri-hydrates) that exist in the second stage of the CHR are modified to be more chemically reactive and caused to be more dense. Certain admixtures are used to cause a greater dispersion of the cement particles in impure environments which in turn will promote better development of the weak IPN (Interpenetrating Polymer Network) bonding function. This function is the slowest reaction of all three functional groups and its primary function is to be the silicate anchor matrix to which all other reaction products attach.

Free Radical and Ion Attack Chemistry

This is a parallel chemistry that can be made up of a wide range of compounds that produce highly reactive ions and complexes in the HWT-20 slurry. This activity does not interfere with the functioning of the other major functional CF groups. This chemical function should attack various toxic organic and inorganic elements within the contaminated medium and reduce them to relatively inert forms or reaction products that can subsequently react with one of the other functional groups in the HWT-20 ACF material. A simple example of this capability is the use of transition metal complexes, but even these must be thought out carefully for one could cause certain counter-productive reactions. An example of this in Figure B-1, Coordination Complexes, and an explanation of the bonding is given in Figure B-2.

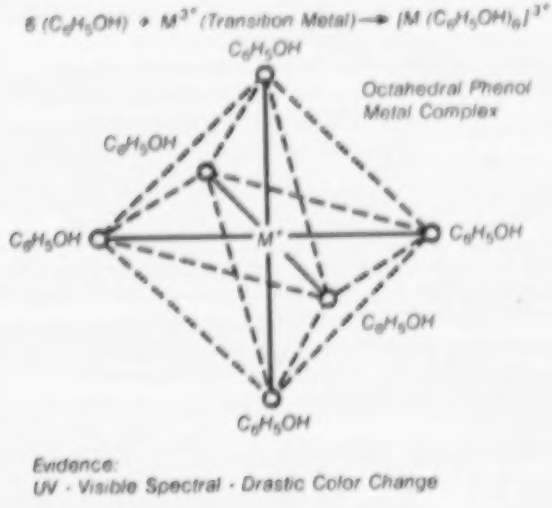


Figure B-1. Coordination complexes.

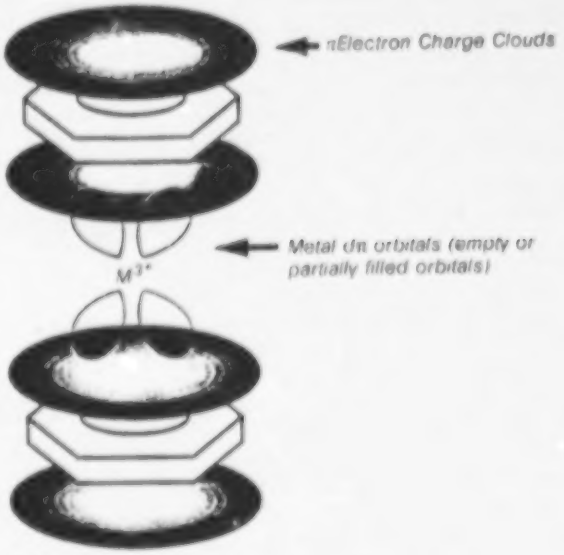
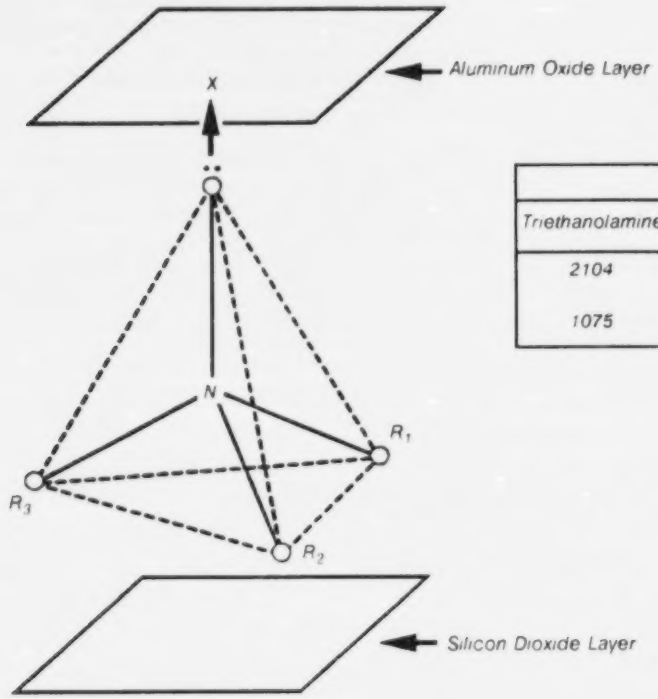

πElectron Charge Clouds
Metal dπ orbitals (empty or partially filled orbitals)
M3+
Evidence:
Shift in FTIR Frequency for Ring Breathing

Figure B-2. Pπ to dπ bonding.

Organophilic Linking Mechanisms--
These are intercalation compounds, such as modified smectite clays, that interact with the organics present, within certain ranges of predetermined selectivity, by a sorptive process in either of two general modes. The strong, short-range bonding is based on a Bronsted and/or Lewis acid or base reaction (see Figure B-3), relative to such a reaction we have observed with triethanolamine. The weak, long ranges forces are basically hydrogen bonds (see Figure B-4), induced dipole or Van der Waals' forces. There can be an initial reaction based on the weak force reaction and later a second strong or Lewis base reaction.

These modified smectite clays have both organic and inorganic properties due to the substitution of the quaternary ammonium ions in the normally inorganic clay structure of the Group IA and IIA for metal ions. This makes them ideal linking mechanisms between the toxic organics in the waste and the cement matrix. The introduction of the quaternary ammonium ions also opens the basal spaces in a pillaring effect to allow like polarity organics into the strong force reaction zone. Bonds can range from weak Van der Waals' forces to strong coordinate covalent bonds.

The important point is that this is primarily a problem in supramolecular chemistry and the multiple and secondary bonding and positioning of the appropriate molecular structures is the key issue. The individual FTIR shifts on functional



FTIR Analysis			
Triethanolamine	Treated	Shift	Peak Assignment
2104	2297	193	Amine Salt Formation
1075	1070	-5	H Bonding

X = Electron Deficient Species or H^+ Which is a Lewis Acid.
Evidence: Shift in N - R (n) Frequency in Positive Direction (Increase)

DSC Analysis - Triethanolamine

Edotherms (°C)	H of Vaporization (Literature) Kcal/mol	Observed H of Vaporization Kcal/mol	Percentage Increase in Energy	Boiling Point (°C)	Highest Endothermic Temperature (°C)
150.97					
337.30	12.78	24.16	89.0	335.4	337.30

Figure B-3. Lewis Acid Base Reactions: Formation of Sigma Bonds (σ).

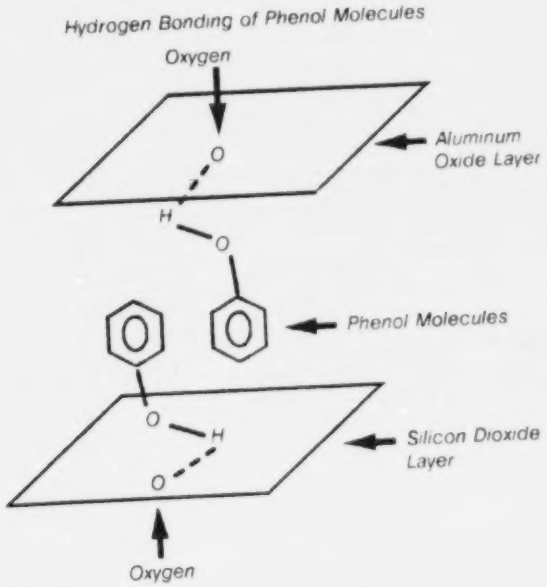
groups seen are usually not considered large and in some cases are slight, but the number of bonds, the sum of the shifts, and the positioning of the bonds is a stronger effect in most cases than one would see in a primary bond. An indication of the strength of this multiple and secondary bonding phenomena can be seen in "Percentage Increase in Energy" of the DSC analysis of a given waste (see Figure B-3). We have also done DSC studies on the treatment of pure phenol, nitrobenzene, and trichloroethylene and have achieved percentage energy increases of 220.7, 275.9, and 52.8 respectively. A significant adjunct condition is that the behavior of a pure substance in a laboratory gives one an idea of what is possible, but in a real, complex waste many other factors will interfere with the ACF material chemistry in achieving the maximum desired effect. There are some positive assisting factors but in most cases one must design ACF materials to overcome a variety of chemical hurdles before the fixation reaction can reach the desired level of efficiency. The use of advanced chemical techniques and analysis provides invaluable insights into the waste chemical mechanisms.

Fourier Transform Infrared (FTIR)--

FTIR studies are used to understand the extent of interaction between the toxic compounds and the HWT-20 ACF material. This analytic technique measures the changes in vibrational motion in specific bond relationships. It also helps to determine the functional elements present in a given molecule involved in a bonding process.

Differential scanning calorimetry (DSC)--

DSC measures the changes in temperature and energies associated with various significant chemical changes involved in bonding, such as the enthalpies of melting, evaporation, decomposition,



Evidence:
Lowering of FTIR Stretching Frequency

Phenol	Treated Phenol	Shift	Peak Assignment
962 cm^{-1}	934 cm^{-1}	-28 cm^{-1}	C - O
3640 cm^{-1}	3632 cm^{-1}	-8 cm^{-1}	H - Bonded OH

Figure B-4. Observed bonding phenomenon in the HWT-23 treatment matrix.

phase transition, etc. This technique can indicate the strength of bonding.

Overview of the In Situ Application

The application of the ACF technology can take place above ground level using a variety of mixing systems or in the ground, in situ, as was done at the former General Electric transformer repair facility in Miami, Florida. The use of high and/or low-pressure rotary shaft injection, with or without mechanical blade mixing, has been done for more than ten to fifteen years in the construction industry for creating injection piles and sub-surface barriers. It was a natural extension of this construction method to be used in the treatment of contaminated soils and sediments, if one had a cement chemistry that would prevent both inorganics and organics from leaching at an unacceptable level. The low pressure rotary shaft injection and blade mixing equipment offered by Geo-Con, Inc. was chosen because it would give an even, homogeneous blending of the HWT-20 ACF with the soil and subsurface porous limestone strata encountered at the site and create accurately placed, consistently overlapping columns. An additional purpose of the in situ method, other than the fact it treats the contaminated soil in-place, is that GE was interested in using this technique of application in sites where there was volatile and semivolatile organic contamination of the subsurface soils where it would not be desirable to expose these soils to the air by a removal technique.

At the SITE Program's Demonstration, Geo-Con used a relatively small diameter drill -- one yard -- for two reasons. The drilling for most of the time was in rock and the objective was to prove the concept of in situ treatment. The mixing drill process could be operated in sand/clay soils with a larger diameter drill (2 to 3 yards) and/or multiple, parallel drills, resulting in a quicker and more economical treatment. In situ treatment costs can be as low as $20 to 30/yard, excluding treatment chemicals, on a large project, up to $60 to 70/yard in difficult situations.

PCB Leaching and Extraction Studies

The HWT-20 CF Series was successfully used in the treatment of PCBs at the General Electric (GE) Miami Site under the U.S. Environmental Protection Agency's Superfund Innovative Technology Evaluation (SITE) Program. This application was done in situ, using mixing drills down to 6.15 meters (m) from Geo-Con, Inc. of Pittsburgh. The first 1.2 m was sand, the second 2.5 m was a porous coral like limestone, and below that quartz sand, with fresh water at 1.2 m. The level of addition of the HWT-20 CF material was 15 wt% to soil. In other words, for every metric ton of contaminated soil 150 kg of dry HWT-20 was added in a slurry form. The maximum concentration of PCBs was 5,700 ppm and was found by GC/ECD. The leaching procedures were the USEPA TCLP (Toxicity Characteristic Leaching Procedure), 18-hour dynamic acetic acid test, ANS 16.1 and the MCC-1P leach procedures. Essentially no PCBs came out in the EPA testing, and only one sample was found to leach in GE's testing, that was 1.2 ppb on a two-week old sample. GE did methylene chloride extractions of drill core samples as well, and did not find in excess of 206 ppm PCBs in the treated samples using GC/ECD.

Some of the pre-project laboratory experiments, carried out by Dr. R. Soundararajan, gave some insights into what was occurring in the treated soil matrix. In a sample of PCB-contaminated soil from the same site and the same sample barrel as the above sample, eight-hour methylene chloride extractions were performed on the untreated and crushed treated samples.

Analysis was done by GC/MS with the machine calibrated against all 221 position-isomers of PCBs. In one sample of this experiment, an admixture was included that produced a sulfurous acid that would totally disable the organophilic clay linking-

mechanisms between the PCBs and the slower-developing silicate-based anchoring matrix. In the second sample, the admixture was removed so that primary linking mechanisms could function. The results are as follows, untreated soil released 28,800 ppm PCBs in a methylene chloride extraction:

	Sample 1: Admixture	Sample 2: No Admixture
Treated extraction	26,437 ppm	2,800 ppm
Treated TCLP	10,437 ppm	12.5 ppm

These tests were done only three days after treatment. A treatment dilution factor of 20% is included in the above numbers. The TCLP numbers did improve with the age of treated sample. This particular sample showed only 5,000-6,000 ppm values using standard GC analysis, mainly because the GC/MS was registered with all 221 PCB isomers. Also high values (40,000-50,000 ppm) of chlorinated benzenes were found, most likely the decomposition products of the PCBs, since no chlorinated benzenes were ever used at the site. The chlorinated benzenes were reduced, in a similar proportion to the reduction in PCBs of Sample 2, from untreated to treated extraction values. Almost all of the existing PCB isomers after treatment were the low value chlorine forms.

The conclusions of the above experiment were supported further in another set of leach and extraction tests performed on a sample of a clay/sand soil contaminated with low levels of PCBs (290 ppm). The eight-hour testing procedure was the same as above, with the focus on which isomers were bonded or retained in the treatment matrix after solvent extraction of crushed treated samples. The TCLP leach tests of the treated material were all non-detectable. The sample cured for seven days. The treatment level of HWT-20 was 15 wt% to the weight of soil. In the untreated soil there was some chlorobenzenes and substituted phenols but none were found in the treated soil. Only the lighter PCB isomers (tri, tetra, and penta) were found in the treated soil. The hexa- and hepta-chlorophenols were not found in the treated. The total PCB content extracted was 190 ppm or 65 wt%.

Relative to PCBs, the current HWT ACF treatment technology is able to alter or bond to a high degree the heavier chlorinated PCB molecules and to a lesser degree the lighter chlorinated molecules. It is very effective in preventing the leaching of PCBs against the TCLP of all types. Also the HWT-20 ACF treatment sufficiently bonds and prevents the leaching of the PCB decomposition products, substituted benzene and phenol compounds. Newer formulations of a more advanced IWT ACF product show significantly greater rates of bonding or chemical alteration of organics, including PCBs. An example of the treatment of a PCB-containing waste with our newer "Polyfunctional Reactive Silicates" (PFRS) (TM) is shown in Figures B-5 and B-6. These ACF materials are based on new inorganic carceplex structures and heretofore non-existent organic trailers. As the results show, this is the most effective PCB reaction to date and the research is continuing to be positive. The first of these new PFRS materials should be commercially available later this year.

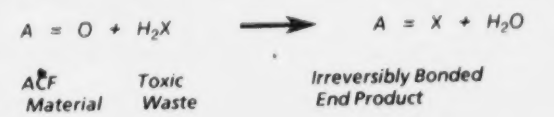
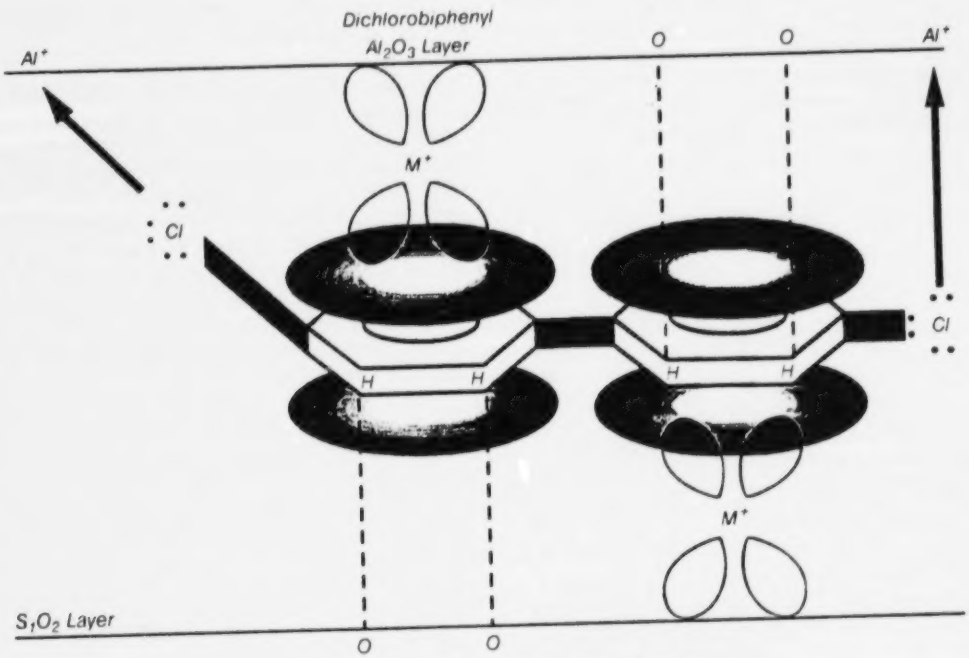


Figure B-5. Formation of Permanent σ + π Bonding (Covalent Bonding).

Treatment by ACF of High Content Organic Waste

An organic content waste with a high percentage of heavy hydrocarbons and with relative trace to small fractional loadings of volatile and semivolatile toxic compounds is normally a difficult material for the usual S/S mixtures to effectively treat, unless some integer multiple by weight of the S/S material is added to the weight of the waste and end-state physical properties are all that is being considered. The waste sample, in this case, was a soil with a heavy concentration of long chain hydrocarbons from

	Untreated extraction	Treated extraction	TCLP
Bis(1-chloro-iso-propyl)ether	8,528 ppm	ND	ND
Naphthalene	18,060 ppm	1,445 ppm	ND
Phenanthrene	20,184 ppm	ND	ND
Benzo(A)anthracene	30,460 ppm	ND	ND



Solvent Extraction and Leach Results:

	Untreated (ppm)	Solvent Extraction of Treated (ppm)	TCLP
PCB	17,580	N.D.	N.D.

FTIR Study of PCB

Dichlorobiphenyl	Treated PCB	Shift	Peak Assignment
1150 cm^{-1}	1118 cm^{-1}	-32	Cl to Al Coordinate Bond

Figure B-6. Supramolecular chemistry/multiple and secondary bonding.

an acid/clay process for recycling used oil. The major organic toxic components of this waste, as determined by a solvent extraction and analyzed by a GC/MS are shown below:

This contaminated sample was treated 50% by weight with an experimental and more advanced chemical fixation material and allowed to cure for only two days. This treatment level is too high for an actual project, but what we were trying to achieve is an accelerated effect that would allow us to examine the bonding activity more quickly by the solvent extraction (GC/MS), FTIR, and DSC analyses. A dilution factor of 50% was used in all quantification. Standard methods of analysis and QA/QC were used.

With such a complex mixture to analyze by FTIR and DSC the approach had to be different than working with a pure, known organic liquid. In using FTIR, we focused on functional groups that we knew were there in relatively large concentrations and looked for shifts within those groups to indicate a level of bonding activity. In reviewing the data, we have found that there were significant shifts in a number of FTIR frequency regions, and hydrogen bonding was occurring between the aliphatic amines, hydroxyl compounds, and the oxygen in the Al_2O_3 and SiO_2 in the CF material. There was an amine salt formation, as the result of a Lewis base reaction at 1,580 cm^{-1}. The most significant shift occurred at 1005 cm^{-1} where a hydrogen bond was formed with an SiO_2. This is explained by the fact that the oxygen in the silica strongly interacted with the hydrogens of alkyl, hydroxyl, and amino groups, which results in a reduction of the O-Si-O bond order (Table B-1, Infrared Data).

The DSC data (TableB-2, DSC Data) also confirms that relatively significant bonding activity is occurring. The enthalpy of vaporization has increased by 54.9% from untreated to treated soil.

The DSC analysis is an energy summation function rather than a focus on a specific reaction.

Aniline Fixation Study

Aniline is considered to be a difficult compound for chemical fixation to control in terms of leaching and is also extremely toxic. IWT ACF products were tested against fourteen other products and mix designs in this treatability study. The objective was to treat the aniline contaminated lime/soil (pH 12.5) material such that the TCLP value was less than 50 ppb. IWT tested successfully using the HWT-9 ACF material and will be used in the remediation project starting in November of 1989 by Geo-Con in an in situ mode.

Cement leach values continued to increase over time. FTIR studies were done on the aniline plus cement and aniline treated by HWT-9 samples. These results supported the premise that there is significant chemical bonding by a different and shifted chemical activity spectra of the HWT-9, particularly in the characteristic absorption bands associated with the aniline molecule as compared to the cement plus aniline.

Treatment of Volatile Organics in a Soil Material with PFRS Materials

In a recent analysis by Kiber Associates, Atlanta, for a major corporation one of IWT's new Polyfunctional Reactive Silicates designs was bench tested in a treatment of spiked soil samples from Miami, Florida, with seven VOCs. The mixing of the samples for the TCLP tests took place in a controlled atmosphere and checked for the degree of volatilization of the VOCs during mixing and curing. Temperature profiles of the samples before and after treatment were also plotted.

Samples were spiked with the following compounds and concentrations: benzene 75 ppm, chlorobenzene 150 ppm, m-xylene 10 ppm, 1,1 dichloroethane 10 ppm, 1,3 dichloropropylene 10 ppm, carbon tetrachloride 10 ppm, and ethyl benzene 10 ppm.

All samples were treated at 15% by weight of the treatment material, with a 30 day cure.

Methanol Extraction of Treated Material - Detectable Extraction Data (ppb)

HWT-20 - 27 benzene, 1072 chlorobenzene, 47 ethyl benzene, 177 xylene

HWT-20M - 591 chlorobenzene

HWT-23H - 444 benzene, 6407 chlorobenzene, 370 ethyl benzene, 262 xylene

PFRS - 320 chlorobenzene

The PFRS material could be altered further to improve the solvent extraction results of the chlorobenzene.

TCLP Leach Data of Treated Material - Detectable Leach Data (ppb)

HWT-20 - 14 benzene, 404 chlorobenzene, 73 xylene
HWT-20M - 306 chlorobenzene
HWT-23H - 364 chlorobenzene
PFRS - 45 chlorobenzene

The temperature of the samples HWT-20 and HWT-23H rose from 17°C to 25°C during mixing and curing, HWT-20M went to 29°C, and PFRS went to 32°C. Total VOCs lost into the air during mixing and curing was 3% for the cooler treated samples and 4.5% for the PFRS and HWT-20M samples. This air leaching should be reduced significantly if the application was done in-place, underground, instead of in the open in an above ground mixer.

Independent analytical work done in The Netherlands on PFRS treated soils contaminated with mercury, arsenic, chlorobenzenes, organo-chloro-pesticides, chloro-phenoxy-pesticides, organo-phosphate pesticides, nitrophenols, chlorophenols, and carbon disulfide against the Dutch availability and leach tests was successful. Testing of these samples in the U.S. by TCLP and solvent extraction procedures was also well inside the EPA limits.

Recent experimental work done by Dr. R. Soundararajan has indicated that lime, lime/fly ash, or pozzolan-based S/S of organic-content waste of a sufficient level (this threshold is not yet known, but certainly the oil recycling waste in this case applies) will generate significant carbon monoxide and/or acetylene gas when exposed to water of even mild acidity. Also, during the process of S/S or CF treatment, it is desirable to keep the heat generation by the reaction with water as low as possible, since the more heat generated the more the volatilization of the organics. The IWT ACF technology only contains trace amounts of lime in the cement fraction of its composition and no pozzolans are used. The rate of addition of the IWT ACF materials used to weigh waste is relatively low, 12% to 20%, and has a lower heat of hydration than straight cement.

Other "tricks" one must watch out for in the field of S/S or chemical fixation are the use of compounds that convert various toxic compounds to other compounds that can be volatilized out of the system during the cement or pozzolan/lime hydration reaction, and/or a masking technique by using certain long chain hydrocarbons such as mineral oil. The way to screen for these is: 1) know the addition rate of the treatment material relative to the weight of the waste; 2) determine whether organic based additives being used; 3) use a GC/MS as the

Total aniline (ppm)	Percent treatment by weight	Untreated TCLP (ppm)	Treated TCLP (ppb)
146 (10 day cure)	20	7.1	ND <1
325 (10 day cure)	20	12.5	110
325 (10 day cure)	30	12.5	ND <1
325 (30 day cure)	20	12.5	ND <1
Cement (32 days)	30	12.5	100

analytical instrument with subtraction filtering; 4) do a complete priority pollutant scan for volatiles and semivolatiles in the treated analysis; 5) consider an air-leaching test during the mixing and hydration phase of the pre-project bench testing and during at least 30 days after if you suspect this approach is being used.

Treatability Studies of Metals and Inorganics

I. Arsenic and Mercury in Soil

Total concentrations - As 43,000 ppm, Hg 5,300ppm

TCLP values after seven days of sample treated at 30% by weight with HWT-11 was the following, As 3.5 ppm and Hg 0.06 ppm. These numbers should go lower as the sample cures further.

II. Chromium +6 and Cyanide

From another site in Alabama the following was obtained from a treatment with HWT-11H compared to treatment by straight Portland cement. Total chromium 6,310 ppm, total cyanide 235 ppm.

Untreated leachate, Cr 37 ppm, CN 0.34 ppm

% Treatment to/weight of soil	Cement Treatment Cr	CN	HWT-11H Treatment Cr	CN
15%	5.25 ppm	0.86 ppm	0.29 ppm	<0.02 ppm
35%	3.93 ppm		BD	BD

BD - below detection

III. Hexavalent Chromium

Waste lagoons contaminated with chromium at 7,155 ppm. Cr+6 leached at 150 ppm. Treatment was at 25% by HWT-11H. The leach data from a one day cure was Cr+6 nondetectable and total chromium leached at 0.15 ppm.

IV. Arsenic, Lead, Copper

A soil sample was contaminated with arsenic 2,200 ppm, lead 670 ppm, chromium 1,250 ppm, and copper at 3,000 ppm. Treated at 15% by weight with HWT-11 the EP Toxicity leach values after a one week cure were arsenic 0.126 ppm, lead nondetectable, chromium 1.1 ppm, and copper 0.22 ppm.

Summation

Chemical fixation technology is far more advanced and cost effective than most people realize, especially from those companies or groups that have done in-depth chemical research of the basic fixation reaction mechanism. International Waste Technologies has and is doing this basic research and believes that the HWT ACF Product Series and the new, more advanced products (PFRS) that will come out in the near future will compete favorably with thermal and biological methods in the destruction, alteration, and/or bonding of organics and the immobilization of inorganics. The effectiveness of ACF technology can be verified analytically, with relative quickness and function in a wide range of contaminated environments at relatively acceptable costs and ease of use factors. An important key to the success of this category of toxic waste treatment is for the regulators and users of this type of technology to insist on high standards of relevant chemical testing and verification in the pre-project treatability analysis and careful QA/QC during project application.

In situ applications that are effective in terms of homogeneity of mixing the ACF material with the contaminated soil to the required level and that do not leave any voids can be an effective, economical, and a necessary part of the waste treatment picture. The Geo-Con system successfully demonstrated that objective.

IWT Response to the USEPA Applications Analysis Report

The EPA has taken a generally critical approach, particularly with respect to the fixation chemistry, in this applications analysis. Based on the drafts we have received to date, the overall reasoning of this position is in general rather curious to us, but

specifically the EPA has been negative in the following nine major points.

1. The EPA has ignored the use of the appropriate types of chemical analysis that would be able to discern whether the IWT chemical fixation material, HWT-20, is in fact chemically bonding with the PCBs to any degree instead of a weak adsorption, encapsulation, dilution phenomena as its total means of waste treatment. The chemical bonding could have been verified by using FTIR and DSC analysis of the PCB-contaminated site material treated with the HWT-20 in a bench top test. The chemical bonding capability to organics of the IWT fixation material is central to IWT's product claims. IWT did perform such analysis on contaminated soil from the site but was unable to convince the EPA to duplicate these tests (see section titled "Vendor Claims", subtitled "PCB Leaching and Extraction Studies"). Their position is that IWT agreed to a test plan in March 1988, which we did. They then took the position that there were no conditions under which the test plan could be amended. The main reason we asked for additional testing to clear up the bonding question was in order to counter the EPA's speculative attack to discount our product claims in the various draft reports it sent to us. The additional testing requested by IWT would have been a relatively small additional cost and certainly it would be warranted in the case of a new technological approach along with all the conventional testing. The analytical procedures needed to be expanded over what had been done in the past to verify our proposed concept. Instead the EPA speculated and implied from a generally uninformed position that, at best, there was no evidence to support this claim. In fact, there is no way to judge what relevant chemical processes are occurring and how effective they are from the analytical work done by the EPA. The claim of chemical bonding with organics is important because it lifts the solidification/ stabilization (S/S) process to a new and important level over what has been done in the past in this field. S/S is relatively inexpensive and easy to use. It is also easy to verify its effectiveness compared with other forms of waste treatment and if it can reach a new and important plateau of quality of treatment, then it is very significant.

2. The EPA used a technology evaluation team of the IWT SITE Demonstration which had a perspective anchored in a concept structure that reflected the antiquated and simplistic notions of chemical fixation as a physical process that should be evaluated like an extension of civil engineering testing. IWT is not taking the position that all physical testing is wrong, only that this evaluation process should have been augmented with some innovative expertise in the area of inorganic/organic chemistry, clay chemistry, and physics. This would have caused the EPA to expand the initially agreed to test plan.

3. The EPA has mentioned many times in this report that the HWT-20 fixation material freeze/thaw results were poor. This may be true from the point of view as a building material, but the EPA had failed to do any leach testing of the treated material that went through the freeze/thaw testing to see if the freeze/thaw process affected in a negative fashion the HWT-20's ability to prevent leaching to an excessive degree. Continued freezing and thawing will break the sample into small pieces. The TCLP leach test requires the sample to be ground to a small grain size and the HWT-20 did well on the TCLP testing. TCLP tests on the samples used in the freeze/thaw tests would have been simple to perform. Also, the chemical fixation material is designed on the basis of many factors. If freezing and thawing were proven an important issue, the mix could be changed to improve its characteristics in that respect. This change is simple cement chemistry. Freezing and thawing are not going to occur from the surface to twenty feet down in Miami, Florida. Also most of the treatment occurred under water, therefore the curing treated mass would acquire a lot of pore water which, when exposed to freeze/thaw cycles, will cause cracking. In the wet/dry weathering test, which is really what will happen in this environment, results were excellent. Permeability results were in the range of what would be acceptable as a liner material.

4. The dilution factor issue of the mixing process of Geo-Con's in situ mixing drill could have been determined absolutely in properly controlled, pre-project bench testing rather than having the EPA speculate about this effect. The EPA postulates that since there is 95% reduction in the presence of metals from untreated to treated B-6 and B-7 samples attributed to mixing, then that should correlate as a one to one mapping to the reduction of the presence of organics. What valid reasoning states that the metals and organics must always congregate in the same area? The majority of outstanding questions relating to the effectiveness of the HWT-20 material revolve around the fact that insufficient pre-project bench testing was done and once the test plan was established many months prior to the actual demonstration it seemed set in concrete. Many of the important questions could have been resolved even after the demonstration by doing chemical bench studies then, but that seemed impossible. It is not IWT's fault that this was not done. We raised the issue time and time again in various written

communications to the EPA project management. The report penalizes us and our technology for these deficiencies. They advised IWT to apply for another study.

5. The EPA buries in the text of this report rather than explaining in the various summaries that this is an actual project for General Electric (GE), not something contrived for an EPA technology demonstration only, and that the requirements placed on IWT and GE by the involved State and Federal regulatory authorities relative to the efficacy of the chemical fixation treatment are tied to PCBs only, and that VOCs were not an issue in terms of treatment at that time. IWT could have added additional compounds into the HWT-20 mixture to improve its ability to reduce leaching of VOCs, but this was not required. Even with this handicap the HWT-20 material affected a drop in the leaching of the total VOCs by a factor of 147 and 13 (see Samples B-6, B-7) and a factor of 36 and 22 in the total content of VOCs. Even relative to the immobilization of metals this report seems to cast doubt on the capability of the HWT-20 chemical fixation material. In contradiction to this implication, the EPA testing shows that the metals passed even drinking water values in the leach testing on the treated material. Further independent testing on the treatment of VOCs was done on various mix designs of IWT chemical fixation materials by a major U.S. corporation and the results are given in the section titled, "Treatment of Volatile Organics in a Soil Material with PFRS". This clearly shows the significant impact of formula changes on the ability to contain and chemically fix VOCs.

6. The EPA refers to test information, reports, and articles given to them by IWT as evidence to support the basically negative premise of this applications analysis. These reports and articles were put together over a four-year period under different requirements while the IWT chemical fixation technology was in the process of evolution, and it still is changing as we learn more. There were not even specific leach value standards set at the time that some of this work was done. The test work reported was always run by independent, credible laboratories working under the prescribed EPA and analytical procedures at the time. This was not a coherent body of work strictly put together for this Applications Analysis Report, it was information given to the EPA for educational purposes on the development of the thinking and experimentation as the technology evolved. It was meant to give them the fundamental issues involved, not be used as evidence against IWT.

7. The EPA explanation of the nature and value of FTIR and DSC analysis is completely lacking and raises the question about their capability and reasoning behind their position in writing this report. Their understanding of bonding is insufficient as well and shows in their explanations in the draft reports we have seen to date.

8. The comments the EPA makes on IWT's lack of field experience seem to us unfair since the regulations and interpretation of these regulations which make the IWT technology viable commercially have only been in effect since late 1987 and the body of regulation that governs what and how waste can be treated by chemical fixation, especially organics to pass TCLP, is still evolving. Even considering this, IWT has gained the confidence of companies such as General Electric and Westinghouse. Both Geo-Con and Westinghouse Environmental are including the IWT advanced chemical fixation technologies in conjunction with their waste treatment marketing. IWT has subcontracted to Westinghouse in completing a 10,000 yd^3 project to treat lead-contaminated soils in Atlanta. General Electric will complete the 8,750 yd^3 Miami Project (which will include the treatment of PCBs, VOCs, and metals) starting in November 1989 using the IWT treatment materials. Region IV-Atlanta of the EPA selected, based on independent testing, IWT to supply the treatment material for a site containing cyanide and hexavalent chromium to drinking water standards. IWT was also selected and has supplied the Italian Government with fixation materials for the first remediation project in Italy under the new regulations that are modeled after the U.S. environmental laws, including the use of the TCLP tests.

9. No matter what IWT claims relative to the ability of its fixation products to treat a given waste, and even if we received an outstanding rating by the EPA in this report, every project situation would require this treatment technology to be proven again and again in appropriate pre-project bench tests, technology reviews, and possibly even pilot project tests. This technology has a wide range of applications, is effective if proper screening is done, and is economical and efficient. The IWT chemical fixation technology and the in situ method of application must not be too bad if three of the EPA technology evaluators used in this project decided to go into business copying at least the form, and to a yet unknown degree, the content of the technology to become competitors of IWT and Geo-Con before this report was even finalized.

EPA HAS TURNED OVER THIS MATTER TO EPA'S OFFICE OF INSPECTOR GENERAL FOR INVESTIGATION.

Geo-Con, Inc. Claims

Geo-Con is generally in agreement with the SITE Demonstration Report as regards comments relating to Geo-Con's Deep Soil Mixing (DSM) System.

We do feel, however, that some clarification is needed pertaining to the report's assertion that "location of the soil columns deviated from the planned points and some untreated areas between columns exist".

In actuality, the locations of most columns were within normal drilling tolerances. One column deviated six inches. A graphical plot was made of actual locations of columns and untreated areas referred to were assumed from that graph, and not found through the coring program. For the most part, the columns created are slightly larger than the nominal thirty-six inch diameter which accounts for minor deviations. In any case, the distance between centers of columns can be shortened to raise the factor of safety against an untreated area. In general, the report confirms that the soil mixing was very effective.

DSM has proven to be an excellent method of mixing slurry with contaminated soils for chemical fixation. A completed DSM fixation project results in a homogeneous mixture of slurry and in situ soils. It appears that the question to answer is what materials would be effective in neutralizing specific pollutants and in what dosages.

There are other proven uses of DSM for environmental applications that are also economical. DSM has been used to construct hydraulic barriers to isolate contaminated soils and prevent contaminated groundwater from leaching into a nearby water source.

DSM was selected over other conventional hydraulic barrier techniques because it does not require any soil to be excavated, thereby eliminating costly backfill and disposal. A cement-bentonite slurry blended with soil to meet the permeability requirements and reinforcing steel was added for structural requirements.

For solidification and stabilization of contaminated soil by DSM, many common materials such as cement, lime, kiln dust, and fly ash can be batched into slurry form and mixed into the soil.

For aerobic bacterial destruction or organic wastes, oxygen can be pumped through the augers and out the tip at high enough pressures to aerate the soil and accelerate its bacterial activity. (Existing applications of aerobic destruction are limited to near surface spills.)

Steam or other heated gases can be injected through the augers to strip the soil of volatile organics. A hood at the surface would evacuate the waste gases to a plant for recover and disposal. This method would decrease the potential for offsite emission that is always present during an "evacuate and remove" type of operation.

Shallow Soil Mixing (SSM) is a variation of DSM. SSM utilizes a single large diameter auger to perform stabilization and fixation projects where the contamination is less than thirty feet deep. It is more economical than DSM at shallow depths because much more soil is targeted at one time.

DSM offers a number of advantages over conventional techniques:

- No excavation is required.
- Treatment at depths up to 150 feet.
- Effective for a wide variety of soil conditions.
- A relatively rapid construction sequence.
- Easy to adjust mix designs and flows.
- No need to dewater.

Geo-Con Background

Geo-Con, in addition to its soil improvement and specialty foundation work, is a full service remedial construction company. Geo-Con has experience in drainage ditches, capping, lagoon/landfilling closures, soil/sludge stabilization, and drum removal. Geo-Con is also a leader in slurry cut-off walls, having installed more than 400 walls to date, including soil-bentonite, cement-bentonite, and soil-attapulgite.

In addition to the DSM soil-fixation project in Hialeah, Florida, Geo-Con has performed the following selected projects:

Site Remediation Stabilization and Geomembrane Installation Sludge Pond Closure/Vickery, Ohio--
The sludge pond closure project conducted in Vickery, Ohio, by Geo-Con in 1986 was the largest privately financed project of its kind in the nation. Approximately 265,000 cubic yards of PCB and dioxin-contaminated metal sludges were stabilized.

Geo-Con first completed a pilot project to demonstrate the technical feasibility of handling and

solidifying the waste with cementitious agents. Eventually, all the sludges on the sites were stabilized, without incident, in the face of keen public awareness and publicity. All solidified sludges, contaminated soil, and debris were stockpiled for temporary storage. All solidification work required EPA Level B and Level C worker protection, which was monitored pursuant to a site-specific health-and-safety plan by in-house industrial hygienists and site safety officer.

The empty and decontaminated sludge ponds were regraded to form one large cell to permanently contain the stabilized sludge. Geo-Con was contracted to construct the RCRA closure cell. The cell will be comprised of a clay liner with three synthetic liners and leachate collection and detection systems. At the time of the writing of this project summary, the capillary barrier system and clay liner had been completed and the synthetic liners were being replaced.

Geo-Con Remediation Experience

Sludge Stabilization and Capping Project - Sparta, Wisconsin--

Geo-Con was selected to perform various services leading to the closure of a metal plating lagoon and dump site in Southern Wisconsin. Geo-Con performed sludge and waste stabilization laboratory studies to determine the most cost-effective acceptable reagents for this particular waste stream. Once the reagent was identified, Geo-Con in conjunction with EDER Associates, the Owner's environmental consultant, prepared health and safety programs and operating plans to support the closure plan.

Geo-Con stabilized over 2,000 cubic yards of sludge on this project and is performing grading operations to allow placement of final cap and cover systems.

Site Remediation - Lagoon Solidification Cap and Landfill Creosote Impoundment/Savannah, Georgia--

Geo-Con closed an unlined lagoon for a wood treatment facility in Savannah, Georgia. This project involved the onsite, in situ stabilization of 12,000 cubic yards of creosote contaminated sludge to attain specified strengths and moisture content. After solidification, the sludge was transferred to an onsite disposal location where the waste was compacted, graded, covered with a clay cap, synthetic liner, and cover materials. All operations were accomplished by Geo-Con forces using EPA Level C and Level D protection equipment along with a "real time" air-monitoring program.

Site Remediation - Deep Soil Mixing Cutoff Wall - Bay City, Michigan--

This project utilized the DSM technique to prevent PCBs from migrating into the Saginaw River. A large manufacturing company required a cutoff wall to contain groundwater contaminated by its operations.

Because the soils were very soft (<1 blow count per foot), a conventional soil-bentonite cut-off wall could not be constructed. The problem was magnified because the alignment of the wall is as close as six feet in some areas to the Saginaw River. If the soil-bentonite trench were to collapse during construction, and if there was a break of adjacent lagoons, there could have been a disastrous spill. The Owner opted for the DSM technique, which produced a 4,500-ft-long impermeable structural wall 35 to 65 ft deep, which was keyed into a subsurface aquiclude. Treating the soil in-place saved the Owner the expense of removal and disposal of the contaminated soil and eliminated a sensitive and complicated operation.

Table B-1. Infrared Data

Waste extract cm-1	Waste extract + binder cm-1	Infrared frequency shift cm-1	Infrared function group assignments
3,394	3,385	-9	OH Stretch O---H....O
3,382	3,372	-10	NH Stretch N---H....O
3,373	3,355	-18	
1,597	1,580	-17	Keto Group C---O....H
1,035	1,005	-30	Hydrogen Bonding Si Si O . . . H

Table B-2. DSC Data

DSC Endothermic Peak Values

	Temperature (Degrees C)	H. (Vaporization) cal. per gram
Waste extract	138.90	18.63
Waste extract + binder	121.2	6.15
	414.4	2.32
	414.5	2.06
		10.53 Total

	Waste extract cal/gram	Waste extract + binder cal/gram
Total H (vaporization)	18.63	10.53
Total H (vaporization) corrected to 100%	---	28.65

	Waste extract + binder
TGA - Percent wt. loss at given temperature range	36.48
PERCENT INCREASE in H (vaporation) for waste extract + binder	54.9

Appendix C
SITE Demonstration Test Results

Introduction

A very narrow scope of soil contaminants exists at the GE electric service shop. The untreated soils measured in two sectors showed a maximum PCB concentration of 950 mg/kg, which was less than one-half the anticipated value based on sampling performed by Law Environmental (LE) for GE. The PCB concentrations appear to be very localized, particularly in Sector B where the higher PCB concentrations were seen. The additive was mixed with the soil by the Geo-Con/DSM equipment, providing vertical, and some horizontal, blending. After soil treatment, which produced a mass increase of 32% due to the addition of HWT-20 and water, the maximum PCB concentration was 170 mg/kg, with only one other sample value above 100 mg/kg. In Sector B, the average PCB concentration of the treated soil (50 mg/kg) was about one-quarter of that of the untreated soil (180 mg/kg) after correcting for the additive volume. These low soil values produced TCLP leachates very close to the detection limit, which made interpretation of the results more difficult.

Although high VOCs were measured -- up to 1,485 mg/kg total -- the VOCs were found in only 3 samples, which were in Sector B. This was insufficient information from which to draw any firm conclusions. Heavy metals, at relatively low concentrations (a maximum of 5,000 mg/kg total), were measured at only the same 3 locations as for the VOCs. Thus, the significance of the results is limited, both due to the small number of samples and low soil and leachate concentrations. In addition, IWT claims that their HWT-20 additive was not tailored for immobilization of VOC and metals, only PCBs.

The analytical data consists of physical and chemical tests on untreated and treated soils from various soil depths between 1 and 17 ft below grade. Clean soil and contaminated soil blends from both Sectors B and C were mixed in the laboratory with Type 1 Portland cements to provide a baseline comparison to the soil treated with HWT-20. The demonstration results are discussed separately in terms of the physical tests, chemical tests and operations.

Results

A large amount of analytical and operating data was obtained, but due to the limitations described above, the program objectives could not be completely met. The detailed results and operating summaries are in the Technology Evaluation Report [4]. The results of the physical testing are shown in Tables C-1 through C-5, at the end of this Appendix.

Physical Results

The physical tests showed that the IWT in situ stabilization/solidification process could readily solidify soils contaminated with PCBs and VOCs. However, the total organics content of the soil tested was very low, mostly under 1.0 wt%, with a maximum of 1.6 wt% at B-6, a location of high VOCs. The process produced a structurally firm material with good physical properties, except under the freeze/thaw weathering testing where large weight losses, more than 5%, were measured on many samples. The moisture content of the treated soil samples averaged about 18 wt%.

On treatment, the bulk density increased approximately 21%, from 1.55 g/mL (96.7 lb/ft^3) to 1.87 g/mL (116.7 lb/ft^3). This was for an average weight addition of HWT-20 and water of 32%. Thus, the volume increased by 8.5%, which is equivalent to about an 18-in. ground rise in Sector B and 14 in. in Sector C. This was confirmed by observation of the ground rise in the two sectors -- a 1 1/2-to-2 ft rise in Sector B and a 1- to 1-1/2-ft rise in Sector C.

The unconfined compressive strengths (UCS) in Sector B averaged 288 psi. This ranged from 75 psi at Sample Location B-19 -- an interface location of relatively poor overlap (based on the mapping of the soil treatment locations by LE) -- to 579 psi at Sample Location B-23 -- a location near the center of a primary column. In Sector C, the UCS averaged

536 psi. This ranged from 247 at Sample Location C-15, to 866 psi at Sample Location C-1, both column centers. The average additive dosage rate in Sector C (0.193 lb additive/lb dry soil) was 13% greater than in Sector B (0.171 lb). Although in some moisture ranges a concentration change affects the UCS of cement, this was not observed at Hialeah. In addition, no effect of bulk density change on the UCS was observed. These UCS values are quite satisfactory, easily meeting the EPA guideline minimum of 50 psi [5] for this type of technology.

The permeability tests showed a reduction after soil treatment from an average of 1.8×10^{-2} cm/s for untreated soil to 4.2×10^{-7} cm/s for treated soils. This treated soil value was slightly greater than the EPA and industry guideline maximum of 10^{-7} cm/s for hazardous-waste-landfill soil-barrier liners. Not only does a low permeability reduce contaminant mobility, but it lessens solid erosion and weathering degradation. This four- orders-of-magnitude decrease in permeability should divert all groundwater around the treated monolith.

The wet/dry weathering tests showed low weight losses, with the absolute losses about 0.3-0.4%. The relative weight losses, compared to the control specimen, were about 0.1%. However, the freeze/thaw results were not satisfactory. Half of the samples tested had relative weight losses of more than 3.0%, the maximum being 30.7%. The weight losses of the control samples for these tests were 0.3%-0.5%. UCS tests on about half of the weathered samples showed that the strength was equivalent to unweathered samples, except when the relative weight loss exceeded 3.0%. Many of the samples from the freeze/thaw tests with high weight losses crumbled at the start of UCS testing. Permeabilities for wet/dry and freeze/thaw samples with moderate weight losses were equal to the unweathered samples.

The microstructural studies, using scanning-electron and optical microscopy and X-ray diffraction analyses, found the treated soil to be dense, homogeneous, and of low porosity. Variations in the vertical and horizontal directions were absent. Thus, it was concluded that the Geo-Con mixing operation was efficient and that a solidified mass with a potential for long-term durability can be produced.

Formulation tests were also performed in the laboratory, where 3 solidified samples were prepared. They used uncontaminated soil and composite soil samples from Sectors B and C with Type 1 Portland cement, instead of HWT-20, at dosage rates of 0.15 and 0.20 lb/lb dry soil. The results showed the bulk densities were equivalent to those of the treated field samples. The UCS values doubled when the dosage rate of cement was increased from 15% to 20% of the contaminated soil. The UCS values for the contaminated soils were about equal to or greater than the values for field samples, and the moisture content was lower, which may have contributed to the higher UCS values.

Chemical Results

Both soil and leachates were analyzed for PCBs, volatile organics and heavy metals. The leachate results were compared to the corresponding soil compositions.

The untreated soil contamination consisted primarily of PCBs (Aroclor 1260), with one localized area in Sector B of VOCs and heavy metals. High PCB concentrations were measured in Sector B, with the maximum being 950 mg/kg, compared to the 5,700 mg/kg value reported by IWT in Appendix B. Other minor discrepancies between information reported in Appendix B and actual results also exist. The maximum PCB concentration measured in Sector C was 150 mg/kg. After soil treatment, the concentrations in Sector B were reduced on average by a factor of about 4, providing a maximum treated-soil concentration of 170 mg/kg. In Sector C, the reduction was only about 25 wt%. This indicates that soil blending during the additive injection operation produced large reductions in concentrations for the samples in Sector B, indicating that the high PCB concentrations measured were localized. Even greater concentration reductions after soil treatment were observed for heavy metals and VOCs. Analyses for VOCs did not provide any evidence of PCB decomposition, which was claimed by IWT. As noted above, the microstructural analyses showed a homogeneous mass, indicating good vertical and horizontal blending.

The treated-soil leachate analyses for PCBs showed all values below the nominal detection limit (for SW-846 Method 8080) of 1.0 µg/L. However, when analyses of 7 treated-soil leachates from the more contaminated areas were repeated at a reduced detection limit of 0.1 µg/L, four samples were found to be below the new detection limit, with the others 0.2 µg/L or less. This compares to untreated soil samples, which had leachate values up to 13.0 µg/L (there was one apparent wild point at 400 µg/L).

Additional information contributing to the determination of PCB immobilization follows. All untreated soil samples (with soil compositions at or above 300 mg/kg) had measurable leachate compositions (above 1.0 mg/L). All untreated soil samples of less than 60 mg/kg had leachate PCB concentrations below detection limits. For the in-between untreated soil concentrations, some leachate had PCB levels above the detection limit (1.0 µg/L), while others did not. All treated soil PCB compositions were 170 mg/kg or less, with most of

them below 100 mg/kg. Twelve samples analyzed using Leach Tests MCC-1P and ANS 16.1 all produced leachates with PCB concentrations below the detection limit (1.0 µg/L). TCLP leach tests on the 4 contaminated formulation samples produced leachate concentrations for PCBs below the detection limit of 1.0 mg/L. Therefore, it appears that the HWT-20 additive may have immobilized the PCBs, but since all the leachate concentrations, from both untreated and treated soils, were so close to the detection limit, more information at higher soil concentrations is required to confirm this conclusion.

The untreated soil with high VOC concentration was located near a former buried drainage drum. The designations for these samples are B-6, B-7 and B-8, which are samples collected in one location at three different depths -- 1-2 ft, 7-8 ft and 11-12 ft below grade. Three VOCs were identified -- total xylenes, ethylbenzene and chlorobenzene -- with the xylenes found in the greatest quantities. The maximum total VOC concentration in the untreated soil was 1,485 mg/kg at Location B-6. After treatment, the VOC concentrations were reduced sharply to a maximum total concentration of 41.3 mg/kg at B-6, with each component reduced approximately in the same ratio. This reduction was probably due to soil blending. However, some other factors -- such as volatilization of VOCs to the atmosphere and excessive holding time of the samples in the laboratory before analyses -- may have contributed significant reductions.

Immobilization of VOCs could not be determined, since only 3 samples were measured, and the treated soil TCLP leachates were quite low, mostly below 100 µg/L (except for xylenes, which were about 300 to 400 µg/L). Meanwhile, the untreated soil TCLP leachates were about 10 times larger for each VOC component, with the maximum total VOC leachate concentration being about 4.4 mg/L. IWT claims that their HWT-20 additive used in this test was not tailored to immobilize VOCs.

The heavy metals, lead, chromium, copper and zinc, were also detected only at Sample Locations B-6, B-7, and B-8. The maximum total concentration was 5,000 mg/kg at B-6, with lead representing about half of the total metals in the untreated soil. A lower proportion of lead was observed in the treated soil samples. The maximum total-metals concentration in the treated soil was only 279 mg/kg, also at B-6. This soil concentration change after treatment is very large, which tends to confirm that the reduction in treated soil concentrations was due primarily to soil blending with low contamination areas. The laboratory methods for metals analysis consists of an acid digestion procedure followed by Atomic Absorption spectroscopy, which will measure each metal, whether or not it was bonded to the additive.

TCLP leachate analyses for total heavy metals in untreated soils ranged from 0.32 to 2.65 mg/L, with zinc showing the highest concentrations and the other 3 metals comprising 30% or less. The treated soil leachates contained very low concentrations of metals, with individual metals at 100 mg/L or less and the total metals concentration ranging from 120 to 210 mg/L. Since only 3 samples are available and the leachate values are low, any immobilization of metals cannot be determined. IWT claims that their HWT-20 additive was not tailored for immobilizing metals.

The results of the chemical analyses are shown in Tables C-6 through C-9 at the back of this Appendix.

Operations

Geo-Con's equipment operations during the demonstration were satisfactory, although some problems were encountered. These difficulties were minor, and with engineering design changes many could have been avoided. The problems were as follows:

- Automatic control of the feed streams (water and HWT-20) to the auger could not be maintained. Eventually manual control was required. This was caused in part by the fact that the additive feed system was oversized because it was designed for a 4-auger machine.

- Flow surges of additives were encountered on many soil columns. The remixing of the soil and additive on the auger upstroke tended to reduce any impact this may have had on treated soil properties.

- A water leak in the auger head occurred, which restricted the use of supplemental water on the last 21 soil columns. GE instructed Geo-Con to continue operations to minimize time loss. An impact on the physical and chemical properties of the treated soil was not observed.

- Positioning of the auger deviated from the targeted locations, producing some untreated areas between soil columns.

- Difficulties were encountered in aligning the auger to start many of the columns, particularly in Sector C. These difficulties produced delays of a few min up to 40 min.

Table C-1. Physical Properties of Untreated Soils - Sector B

Sample designation(a)	Moisture content %	Bulk density g/mL	pH	Oil & grease %	TOC mg/kg	Permeability x 10^2 cm/s(b)
B-1	2.8	1.50	-	< 0.1	2,100	1.6
B-2	3.0	1.56	7.7	0.1	1,300	1.0
B-3	6.4	1.21	8.4	< 0.1	2,900	1.0
B-4	4.4	1.41	7.6	0.1	2,500	0.76
	4.7	1.55	7.5	< 0.1	1,600	0.50
B-5	3.6	1.28	7.3	0.1	2,600	1.2
B-6	13.3	1.46	11.2	0.8	16,000	1.4
B-7	13.3	1.74	8.3	1.6	12,000	6.0
B-8	16.8	1.85	8.1	0.4	3,100	0.98
B-9	24.8	1.59(c)	7.8	< 0.1	< 100	0.15
B-10	6.3	1.25	8.5	< 0.1	< 100	2.6
B-11	34.9	1.58	7.8	0.2	8,100	0.05
B-12	15.6	1.52	8.1	< 0.1	920	0.91
		1.63				
B-13	22.5	1.46	7.8	0.3	1,500	0.05
		1.73				
B-14	3.2	1.52	7.7	0.1	320	0.98
B-15	9.7	1.83	8.1	0.8	960	2.1
		1.46				
B-16	7.5	1.30	7.9	0.1	11,000	3.7
B-17	12.4	1.85	8.2	0.8	9,900	0.13
	12.3	1.32	8.3	0.7	9,400	0.55

(a) Sample depths
B-1, 2, 3, 4, 5, 6, 10, 14, 16 at 1-2 ft
B-7, 11, 15, 17 at 7-8 ft
B-8, 12 at 11-12 ft
B-9, 13 at 16-17 ft

(b) Each value shown is the permeability multiplied by 10^2. For example, the B-1 permeability is 1.6×10^{-2}, and when multiplied by 10^2 is reported as 1.6.

(c) Modified bulk-density test using split spoon.

Table C-2. Physical Properties of Untreated Soils - Sector C

Sample designation(a)	Moisture content %	Bulk density g/mL	pH	Oil & grease %	TOC mg/kg	Permeability x 10^2 cm/s(b)
C-1	16.7	1.37	8.6	0.4	5,200	0.58
C-2	14.6	1.29	8.5	<0.1	1,800	24.0
C-3	17.1	1.67	8.2	0.4	8,200	3.6
	14.8		8.2	0.2	6,600	0.27
C-4	9.1	1.41	8.7	0.2	1,700	2.1
C-5	9.1	1.28	8.3	0.2	1,100	7.0
C-6	5.7	1.46	8.6	<0.1	2,000	1.0
C-7	20.2	1.74	8.5	<0.1	3,200	0.84
C-8	14.7	1.85	8.4	<0.1	800	0.83
		1.60				
C-9	5.9	1.60	8.6	<0.1	2,500	3.5
		1.74				1.7
C-10	8.2	1.63(b)	8.5	<0.1	1,800	1.3
C-11	19.5	1.39(b)	8.5	<0.1	1,100	1.1
C-12	5.7	1.63	8.7	<0.1	1,600	2.0
C-13	12.5	1.82	8.4	0.2	2,400	0.18
C-14	23.5	1.63	8.3	<0.1	1,500	0.35
		1.59(b)				
C-15	5.3	1.66	8.7	<0.1	2,400	0.81
C-16	15.1	1.20	8.6	<0.1	1,300	12.0
C-17	23.2	1.65	7.9	<0.1	1,300	0.27
		1.60(b)				

(a) Sample depth
C-6, 9, 12, 15 at 1-2 ft
C-1, 2, 3, 4, 5, 7, 10, 13, 16 at 7-8 ft
C-8, 11, 14, 17 at 11-12 ft

(b) Modified bulk-density test using split spoon.

Table C-3. Physical Properties of Treated Soils - Sector B

Sample designation	Moisture content %	Bulk density g/mL	Compressive strength, psi	Permeability x 10^7 cm/s(h)	Weathering tests wt. loss % (a)	
					W/D	F/T
B-1	15.7	1.78	492	1.4	0.38	0.65
B-2	9.9	1.72	330	---	0.32	1.48
			508			
B-3	20.3	1.74	172	3.3	0.37	2.07
B-4	17.6	1.81	206	0.8	0.42	3.34
B-5	31.1	1.66	86	2.3	0.37	
B-6	23.1	1.77	114	4.2	0.43	1.84
	12.9	1.75	115		0.49	
B-7	24.7	1.81	173	21.0		3.04
B-8	19.0	1.88	303	5.9	0.34	27.92
B-9	15.5	1.96	470		0.53	29.53
B-10	--	--	--			
B-11	12.9	2.24	321			
B-12	--	2.15	204			
B-13	--	--	--			
B-14	20.2	1.78	221		0.44	1.66(f)
B-15	21.2	1.83	256		0.40	6.06(g)
B-16	26.5	1.81	413			4.37
B-17	13.3	1.82	507		0.26	1.10
B-18	--	--	--			
B-19	19.1	1.58	75	11.0		
B-20	17.6	1.79	199	2.6	0.46	0.87
B-21	18.1	1.92	479	8.3	0.39(b)	1.34(d)
B-22	20.9	1.99	428	4.1	0.39(c)	6.05(e)
	22.9	1.76	177			
B-23	17.2	1.98	579	3.5	0.27	23.28
B-24	20.1	1.90	351	3.5	0.41	10.73

(a) Reported as % loss of starting weight on a dry basis. The weight losses of the wet/dry (W/D) and freeze/thaw (F/T) controls were 0.3-0.4%.
(b) Permeability after 12 W/D weathering cycles = 2.7×10^{-7} cm/s.
(c) Permeability after 12 W/D cycles = 4.9×10^{-7} cm/s.
(d) Permeability after 12 F/T cycles = 8.9×10^{-8} cm/s.
(e) Permeability after 12 F/T cycles = 1.2×10^{-7} cm/s.
(f) Permeability after 12 F/T cycles = 3.9×10^{-8} cm/s.
(g) Permeability after 12 F/T cycles = 5.9×10^{-7} cm/s.
(h) All values shown are the permeability multiplied by 10^7. For example, B-1 permeability is 1.4×10^{-7}, and when multiplied by 10^7 is reported as 1.4

Table C-4. Physical Properties of Treated Soils - Sector C

Sample designation	Moisture content %	Bulk density g/mL	Compressive strength, psi	Permeability x 10^7 cm/s (d)	Weathering tests wt loss % (a)	
					W/D	F/T
C-1	18.8	1.97	866	0.24	0.35	2.06
C-2	14.3	1.93	528		0.41	8.11
C-3	20.9	1.95	482		0.27	3.94
	17.9	2.01	611		0.31	30.75
C-4	20.2	1.96	656		0.38	2.53
C-5	14.6	1.95	294		0.40	3.12
C-6	12.3	1.91	567	1.0	0.34	1.65
C-7	16.7	1.82	343	6.4	0.31	1.97(b)
	20.0	1.91	524		0.38	
C-8	15.9	2.00	813	4.1	0.39	0.72
C-9	20.8	1.95	460		0.32	1.70
C-10	18.9	1.93	466		1.68	0.88
C-11	19.7	1.97	783		0.27	0.99(c)
C-12	23.8	1.84	409	1.6	0.40	4.20
C-13	15.5	1.99	553	1.9	0.25	8.04
C-14	13.5	1.99	636	2.2	0.31	20.98
C-15	18.0	1.80	247		0.33	2.14
C-16	15.4	2.02	435	4.6	0.30	2.57
C-17	16.7	2.02	521	2.5	0.29	2.95
C-18	16.1	1.91	530		0.32	14.45

(a) Reported as % loss of starting weight on a dry basis. The weight losses of the controls were 0.3-0.4%.
(b) Permeability after 12 F/T cycles = 2.3×10^{-7} cm/s.
(c) Permeability after 12 F/T cycles = 3.0×10^{-8} cm/s.
(d) All values shown are the permeability multiplied by 10^7. For example, C-8 permeability is 4.1×10^{-7}, and when multiplied by 10^7 is reported as 4.1.

Table C-5. Results of Formulation Studies

Property	Addition Rates					
	Clean Soil		Sector B		Sector C	
	15% cement	20% cement	15% cement	20% cement	15% cement	20% cement
Slump flow, %	139.8	102.8	58.1	79.7	129.7	116.5
Moisture content, %	3.6	4.0	5.1	5.0	8.9	8.9
Bulk density, g/mL	2.01	2.02	2.01	2.03	1.88	1.81
UCS, psi	740	1,770	1,332	--	170	318
TCLP PCBs (Aroclor1260), µg/L	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

Table C-6. PCBs in Soils and Leachates - Sector B

Sample designation	PCB concentration			
	Untreated soil mg/kg	Untreated soil TCLP leachate, µg/L	Treated soil mg/kg	Treated soil TCLP leachate, µg/L
B-1	52	< 1.0	40	< 1.0
B-2	74	1.2	53	< 1.0
B-3	55	1.0	40	< 1.0
B-4	88	1.1	41	< 1.0
	78	1.6		
		(0.62)		(< 0.1)
B-5	16	< 1.0	18	< 1.0
B-6	650	12.0	35	< 1.0
			63	< 1.0
		(15)		(0.15)
B-7	460	400.0	82	< 1.0
		(250)		(0.12)
B-8	220	< 1.0	9.6	< 1.0
B-9	16	< 1.0	< 1.0	< 1.0
B-10	1.1	< 1.0	--	--
B-11	950	7.2	170	< 1.0
		(0.33)		(< 0.10)
B-12	140	1.1	16	< 1.0
B-13	250	< 1.0	--	--
B-14	26	< 1.0	11	< 1.0
B-15	63	13.0	7	< 1.0
B-16	300	3.7	100	< 1.0
		(0.50)		(< 0.10)
B-17	490	4.2	100	< 1.0
	500	1.8		(< 0.20)
		(1.0)		
B-18	--	--	--	--
B-19	--	--	97	< 1.0
B-20	--	--	50	< 1.0
B-21	--	--	60	< 1.0
B-22	--	--	130	< 1.0
			98	< 1.0
B-23	--	--	< 1.0	< 1.0
B-24	--	--	1.6	< 1.0

( ) Repeat analyses of existing TCLP leachates analyzed to a detection limit of 0.1 µg/L. Original analyses performed to a detection limit of 1.0 µg/L.

Table C-7. PCBs in Soils and Leachates - Sector C

Sample designation	PCB concentration			
	Untreated soil mg/kg	Untreated soil TCLP leachate, µg/L	Treated soil mg/kg	Treated soil TCLP leachate, µg/L
C-1	98	< 1.0	20	< 1.0
C-2	2.5	< 1.0	19	< 1.0
C-3	96	< 1.0	110	< 1.0
	92		3.5	< 1.0
C-4	9.1	< 1.0	40	< 1.0
C-5	27	< 1.0	22	< 1.0
C-6	16	< 1.0	26	< 1.0
C-7	150	< 1.0	16	< 1.0
			27	< 1.0
C-8	15	< 1.0	5.9	< 1.0
C-9	17	< 1.0	20	
C-10	86	< 1.0	80	< 1.0
				(< 0.10)
C-11	16	1.3	45	< 1.0
C-12	23	< 1.0	4.7	< 1.0
C-13	32	< 1.0	1.2	< 1.0
C-14	1.8	< 1.0	1.0	< 1.0
C-15	80	< 1.0	17	< 1.0
	46			
C-16	13	< 1.0	6.0	< 1.0
C-17	< 1	< 1.0	< 1.0	< 1.0
C-18	--	--	7.1	--

( ) Repeat analysis of existing TCLP leachate analyzed to a detection limit of 0.1 µg/L.

Table C-8. Total Volatile Organics in Soils and Leachates

Sample designation (a)	Untreated soil mg/kg	Untreated soil leachate µg/L	Treated soil mg/kg	Treated soil leachate, µg/L
B-6				
Total xylenes	1,300	3,700	35.0	30
Chlorobenzene	65	280	1.9	< 5
Ethylbenzene	120	440	4.4	< 5
Total	1,485	4,420	41.3	30
B-6d(b)				
Total xylenes	--	--	32.0	< 13
Chlorobenzene	--	--	2.2	< 13
Ethylbenzene	--	--	4.6	< 13
Total			38.8	< 13
B-7				
Total xylenes	560, 1000(c)	6,600	34.0	430
Chlorobenzene	20, 150	290	2.5	54
Ethylbenzene	74, 28	1,000	4.5	120
Total	916 avg.	7,890	41.0	604
B-8				
Total xylenes	140, 190(c)	2,100	1.7	270
Chlorobenzene	5, 7	100	< 1.2	19
Ethylbenzene	13, 23	290	0.66	36
Total	189 avg.	2,490	2.4	325

(a) Depth of samples: B-6 at 1-2 ft; B-7 at 7-8 ft; and B-8 at 11-12 ft.
(b) Duplicate.
(c) Values shown represent two soil analyses.

Table C-9. Total of Four Priority Pollutant Metals in Soils and Leachates

Sample designation*	Untreated soil mg/kg	Untreated soil leachate µg/L	Treated soil mg/kg	Treated soil leachate, µg/L
B-6				
Chromium	400	10	50	40
Copper	910	240	39	60
Lead	2,500	200	140	70
Zinc	1,000	2,200	50	40
Total	4,810	2,650	279	210
B-7				
Chromium	43	10	47	40
Copper	70	20	12	50
Lead	310	< 50	55	< 50
Zinc	240	290	80	30
Total	663	320	194	120
B-8				
Chromium	84	10	46	30
Copper	59	20	6	40
Lead	280	100	11	< 50
Zinc	190	300	17	100
Total	613	430	80	170

* Depth of samples: B-6 at 1-2 ft; B-7 at 7-8 ft; and B-8 at 11-12 ft.

Appendix D
Case Studies

Data in this Applications Analysis Report have been quoted from case studies provided by IWT and GE. A summary of each of these sources is included in this appendix and designated below.

D-1 Report of Initial Bench Scale Testing Solidification/Fixation Agent Evaluation, 8/86

D-2 Letter Report: Report on Chemical and Physical Laboratory Analyses for Bench Scale Specimens, 10/10/86

D-3 Data Sheets from Southwestern Laboratories

D-4 Presentation of the HWT Chemical Fixation Technology and Japanese In-Place Treatment Equipment

D-5 Advanced Chemical Fixation of Organic and Inorganic Content Wastes

D-6 Economic Analysis: Letter from Geo-Con, Inc. to Foster Wheeler Enviresponse, 8/30/88

Case Study D-1

Law Environmental Report to General Electric: Report of Initial Bench Scale Testing Solidification/Fixation Agent Evaluation

Description

A laboratory study was conducted by Law Environmental for General Electric to determine the effectiveness of the International Waste Technologies HWT-20 additive. Thirty-gallon samples from the quartz/sand top-soil layer were collected, based on high, medium or low concentrations of PCBs. The average concentrations of these samples were 5,628, 1,130, and 83 ppm PCBs, respectively. In addition, a sample was collected from a limestone layer (5-10 ft below grade), which had a concentration of 73 ppm PCBs. From each of the four 30-gal soil samples, 3 specimens were taken for laboratory analysis of total PCBs.

For each of the three 30-gal sand-samples, 6 batches (18 total) were prepared; on treatment with the additive, each batch filled 10 molds, 3 in. dia. by 6 in. long. From the limestone sample, 2 batches were prepared. Each batch prepared (total of 20) used a different additive concentration, ranging from 0.03 to 0.25 lb/lb dry soil, at a different moisture range, representing soil either above and below the water table.

Testing Protocol

The following physical tests were performed on untreated soil samples:

Particle size distribution .....ASTM D-421-85 and D-422-63

Permeability (constant head) ...ASTM D-2434-68 (reapproved 1974)

Moisture-density relation .....ASTM D-698-78, Method A

Moisture content ..... ASTM D-2216-80

Chemical analyses of the soil samples were performed using EPA SW-846 Method 3550 for sample preparation, and Method 8080 for PCB analyses.

Four different leaching procedures were used to evaluate the effectiveness of the HWT-20 additive:

EP Toxicity (standard) with membrane filter.

EP Toxicity with glass fiber filter.

EP Toxicity with glass fiber filter and site water plus sulfurous acid (pH = 5) as the leaching medium.

Toxicity Characteristic Leaching Procedure (TCLP) using extraction fluid #2.

Major Conclusions

No conclusions are presented in this document.

Data Summary

The measured physical properties on the untreated soils were:

Particle size distribution -- Typical for Hialeah area (distributions not provided)

Compaction test -- Maximum dry density 103 lb/ft^3 at an optimum moisture content of 10 wt%

Permeability -- 7.4 x 10^{-3} cm/s (one sample)

The leachate results for the 4 leach tests of pre- and posttreatment samples were as follows:

Untreated soil concentration mg/kg	Addiotive rate lb/lb dry soil	Leachate results, µg/L(a) EP Tox, membrane	EP Tox, glass fiber	EP Tox, site water	TCLP
1,130	0.15	3.0 / 1.2	54 / 10	13 / 2.6	10 / 28
1,130	0.18	2.0 / 2.0	54 / 3	13 / 5.5	10 / 14
5,628	0.05	7.0 / 7.0	39 / 39	65 / 98	33 /119
5,628	0.25	2.0 /< 1.0	39 / 4	65 / 32	33 /170
73 (b)	0.15	< 1.0 /< 1.0	5 /< 1.0	4 /< 1.0	1.3 /3.0

(a) Pretreatment/posttreatment
(b) Limestone

The EP Toxicity (EP Tox) tests showed reductions in PCBs in the leachate of the treated soil samples compared to that of untreated soil samples over and above that which would occur from dilution from the additive. The TCLP leachates for the treated soils all had higher PCB concentrations than the untreated soil. Law Environmental had no explanation for the latter results.

In addition, LE found that there was an optimum ratio of weight-of-additive/weight-of-water for maximum treatment effectiveness. This value is in the range of 1.0 to 1.5. Since there was a consistency among the 3 EP Tox tests, the validity of the EP Tox results, compared to the TCLP results, is enhanced.

Case Study D-2

Law Environmental Letter Report to General Electric: Report on Chemical and Physical Laboratory Analyses for Bench Scale Experiments

Description

The description provided for Case Study D-1 is applicable here.

Testing Protocol

This work consists of analyses that were part of Case Study D-1, but issued subsequent to the initial report. The results provided are for the treated-soil physical properties, which were not included in the first case study. The following physical tests were performed on treated soil samples:

Moisture content ..... ASTM D-4216
Dry unit weight ..... Weight/volume
Permeability (falling head) ..... "Test method for solid waste characterization," Section 13
- Unconfined compressive Strength ... ASTM D-2216-80

Major Conclusions

No conclusions presented.

Data Summary

Additive rate lb/lb dry soil	Moisture content before/after, %	Density dry lb/ft^3	UCS(a) psi	Strain at failure, %
0.15	7.6 / 2.8	99.3	198	0.427
0.10	9.5 / 5.4	103.2	310	0.351
0.20	10.1 / 4.1	102.8	299	0.347
0.10	24.4 /13.1 (b)	92.1	367	0.373
0.15	24.5 /13.6 (b)	92.5	714	0.472
0.18	20.9 /11.4 (b)	108.5	1,223	0.737
0.25	19.7 / 9.8 (b)	116.4	2,127	1.07
0.15 (c)	19.8 / 9.6 (b)	115.4	1,899	0.936
0.15 (d)	24.5 / --	92.7	--	--

(a) All height-to-diameter ratios were 2.1 except in the first test, which used a ratio of 1.9.
(b) Moisture content simulating values found below watertable.
(c) Limestone - all other samples are treated quartz sand.
(d) Permeability was 7.6 x 10^{-6} cm/s.

Some additional treated-soil leachate results were provided subsequent to this letter report. In these tests, the HWT-20 was added as a slurry to the soil from the same 30-gal batches of contaminated soil as described in Case Study D-1 (previous tests used dry additive) to more closely simulate field operations. The results were as on the next page:

Average PCB concentration in untreated soil, ppm	Additive rate lb/lb dry soil	Average PCB concentration in treated soil, mg/kg	EP Tox leachate µg/L
1,130	0.15	893	2.45
5,628	0.15	3,942	4.15
5,628	0.15(a)	2,844	4.46
5,628	0.20(a)	3,261	4.13
5,628	0.15(a)	2,929	2.84(b)

(a) Moisture content simulating below watertable.
(b) Used EP Tox with glass fiber filter, substituting site water (no PCBs) for de-ionized water in the extraction. All EP Tox tests replaced the standard membrane filter with a glass fiber filter.

Case Study D-3

Data Sheets from Southwestern Laboratory

Description

Samples were collected from 2 core borings by LE during the demonstration. One boring was at an anticipated poorly tested area (B-3) -- based on information compiled by LE on Geo-Con auger-injection locations -- and the other was near a treated-soil column center (B-2). Samples were collected at level increments of 18 to 24 in. and analyzed for PCBs. TCLP leach tests were then performed on each sample with PCB concentration measured to a detection limit of 0.1 µg/L

Testing Protocol

The samples were cured for approximately 2 weeks before the TCLP leach tests were performed. The leachate analyses were performed 7 days after the extraction.

Major Conclusions

No conclusions are provided with the data.

Data Summary

Sample designation(a)	Depth, ft	PCBs in soil, mg/kg (b)	PCBs in TCLP leachate, µg/L
B-2	3.0 - 3.6	34.9	1.20
B-2	9.0 - 9.75	182.0	<0.10
B-2	7.0 - 7.8	206.0	0.22
B-2	9.5 - 11.0	166.0	0.12
B-2	12.5 - 14.0	32.8	<0.10
B-2	15.5 - 17.0	13.7	0.11
B-3	1.5 - 3.0	22.8	<0.10
B-3	3.0 - 4.5	47.7	<0.10
B-3	6.0 - 7.5	72.7	<0.10
B-3	7.5 - 9.0	97.4	<0.10
B-3	10.5 - 12.0	2.0	<0.10
B-3	13.5 - 15.0	1.0	<0.10
Blank	---	<1.0	<0.10

(a) These designations are those of LE and are not related to those reported earlier in this report.
(b) PCBs - Aroclor 1260

Case Study D-4

Presentation of the HWT Chemical Fixation Technology and Japanese In-Place Treatment Equipment

Description

This is an informal report prepared by IWT describing the technology. In the report, IWT claims that their HWT components have the physical characteristics of sorption, where all free water is absorbed, and of pozzolan-Portland cement where micro-encapsulation occurs in conjunction with the chemical alteration of the toxic character of the waste. This stabilization, they say, is a technological improvement over the successful approaches that have been used by the Japanese since 1970 on large-scale waste cleanups.

It is claimed that the HWT set of chemical fixation products generate complex crystalline inorganic-polymers. These macromolecules are made up of selected polyvalent inorganic elements that react in a polyfunctional manner, producing branched and cross-linked polymers of sufficient density to cause some interpenetrating-polymer-network (IPN) bonding. These polymers are said to have a high resistance to acids and other naturally existing deteriorating factors. Structural bonding in the polymer is mainly covalent. There is a two-phased reaction in which the toxic elements and compounds are complexed first in a fast reaction, and then permanently complexed further in the building of macromolecules, which continue to generate over a long time.

The first part of the chemical fixation generates irreversible colloidal structures and ion exchanges with toxic metals and organics by special intercalation compounds. Phase two is the generation of the macromolecule framework. This is also a relatively irreversible colloid synthesis, which is a slower-moving reaction going from soil-mix to gel, to crystalline, three-dimensional inorganic polymer. The treated material should be able to pass the required leaching tests within 7 to 28 days. By varying the composition of the HWT treatment compounds, the bonding characteristics and durability of the structure are varied to suit a particular waste situation and desired leaching standards.

This paper also describes various in situ technologies used in Japan. The original plan of IWT was to use the JST Method of deep-soil-mixing of Japan National Railways and Sanwa Kizai Co., Ltd. This was subsequently changed to the Geo-Con, Inc., deep-soil-mixing equipment.

Testing Protocol

The earliest leach tests performed by IWT for wastes treated with HWT-20 are described. These tests included:

EP Toxicity for PCBs
Hexane Extraction for Pentachlorophenol (PCP)
TCLP for K051, API separator bottoms
TCLP for a sludge containing 70% water
TCLP for a liquid waste

The hexane extractions show the amount of available contaminant that can be released from the waste. IWT is claiming that chemical bonding exists between HWT-20 and the contaminants, and if hexane or methylene chloride cannot extract it, then it is bonded and unavailable to leaching also.

Major Conclusions

No conclusions are presented in the document.

Data Summary

Contaminants	Concentration in waste, mg/kg	Type of waste	Extraction test	HWT-20 additive, lb/lb dry	Cure time, days	Extractant concentration, mg/L
PCB	1,140	Soil	EP-Tox	0.15	14	0.006
PCB	1,140	Soil	Hexane	0.15	14	355
PCB	6,000	Soi	EP-Tox	0.25	28	0.00008
PCB	6,000	Soil	Hexane	0.25	28	1,300
PCP	11,000	Soil	Methylene chloride	0.15	14	450
PCB	1,800	Oily liquid	EP-Tox	0.20	3	0.069
PCB	9,200	Oily liquid	EP-Tox	0.20	3	0.337
PCP	290-500	Soil	Hexane	0.05	28	38
PCP	290-500	Soil	Hexane	0.10	28	2.3
PCP	290-500	Soil	Hexane	0.15	28	0.26
Cr	630	K051	TCLP	0.15-0.25	*	0.03-0.04
Pb	332	K051	TCLP	0.15-0.25	*	0.05
Ethylbenzene	10	K051	TCLP	0.15-0.25	*	< 0.01
Xylenes	83	K051	TCLP	0.15-0.25	*	< 0.01
Anthracene	19	K051	TCLP	0.15-0.25	*	< 0.01
Chrysenene	29	K051	TCLP	0.15-0.25	*	< 0.01
Methylnaphthalene	470	K051	TCLP	0.15-0.25	*	< 0.01
Naphthalene	93	K051	TCLP	0.15-0.25	*	< 0.01
Phenanthrene	206	K051	TCLP	0.15-0.25	*	< 0.01
Acrylonitrile	120	Sludge	TCLP	0.15	*	1.5
Acrylic Acid	5	Sludge	TCLP	0.15	*	0.1
Acrolein	59	Sludge	TCLP	0.15	*	0.5
Acetonitrile	150	Sludge	TCLP	0.15	*	3.9
Cu	78	Sludge	TCLP	0.15	*	0.2
Sb	13	Sludge	TCLP	0.15	*	0.7
Vinyl chloride	1,671	Liquid	TCLP	0.33	28	ND
Trichloroethylene	11,200	Liquid	TCLP	0.33	28	ND
Trichloroethylane	3,800	Liquid	TCLP	0.33	28	ND
Tetrachloroethylene	5,900	Liquid	TCLP	0.33	28	ND

*Not provided. ND = Nondetected; detection limit not defined.
The PCB and PCP tests show that only a small fraction of these contaminants are extracted by hexane or methylene chloride.

The PCB and PCP tests show that only a small fraction of these contaminants are extracted by hexane or methylene chloride.

Case Study D-5

Advanced Chemical Fixation of Organic and Inorganic Content Wastes

Description

This is an informal IWT report, a followup to the one described in Case Study D-4. It describes test results using a more-advanced additive called HWT-22. The paper describes IWT's view of the mechanisms for the additive bonding to the contaminants. Results are also presented from various extraction tests and from infrared scanning and differential scanning calorimetry (DSC). These latter tests are performed to show changes in the treated waste structure. The infrared scanning shows shifts in vibrational frequencies between atoms, and DSC measures changes in energy and temperature to release the contaminants from the soil.

IWT claims a number of unique properties associated with the additives, which are:

- The inorganic polymer network can be used as a durable medium with a wide range of types of bonding with organics and inorganics.
- An impact on cement hydration reactions that causes a more effective dispersion of treatment chemicals throughout the waste.
- Promotion of surfactant functions that promote microscopic homogeneity.
- Use of intercalation, or linking, compounds to interact with the organic toxins by a sorptive process. The intercalation compound can be sodium bentonite (or another clay) that has been reacted with a quaternary ammonium compound. The nature of the amine can be varied depending on the class of organic toxins to be immobilized.

The paper provides detailed discussion of the bonding mechanisms.

Testing Protocol

Two sets of extraction tests not included in Case Study D-4 are reported, one using TCLP and the other using solvents of differing polarities. This latter test was performed to show the strength of bonding of various contaminants of different polarity.

Various organic compounds were selected for a series of infrared and DSC experiments to better understand the bonding mechanism. The infrared test measures bond lengths after waste treatment and compares them to the bond length in the untreated contaminant. The DSC test was performed to measure the energy necessary to release the compounds from the matrix.

Major Conclusions

The following conclusions are provided by IWT on its test work:

- There is true multiple bonding between HWT-22 and organic components of the waste.
- When heat is applied, many of the organics fragment into simpler molecules.
- The total energy to drive organics out of the treatment mix is higher than their normal heats of vaporization.
- Gas chromatography/mass spectroscopy (GC/MS) data indicate that other bonding reactions are catalyzed by clay additives.

- The use of processed intercalation compounds chemically alters many classes of organics. These compounds, combined with cement, blend into a chemical fixation material that is a viable alternative to other more costly methods of waste treatment.

Data Summary

- The following TCLP leach-test results were obtained by adding 0.15 lb HWT-20/lb dry waste (before thickening) to K049 slop oil emulsion, which also contained some K048, dissolved air flotation float from the refinery industry, and K051 API separator bottoms. Kiln dust was added to the liquid waste on a 1/1 ratio to thicken before the HWT-20 was added. Curing time was 21 days, and a volume expansion of 25% was experienced.

Contaminant	Concentration mg/kg	TCLP leachate concentration mg/L	Contaminant	Concentration mg/kg	TCLP leachate concentration mg/L
Cr	1.9	0.28	Ni	6.3	0.02
Pb	16.3	0.08	V	173.1	0.2
As	4.8	0.0009	xylenes	26,500	4,605
Ba	22.1	1.4	4-methylphenol	9.1	ND
Cd	2.4	0.04	isophorone	2,226	8.5
Hg	1.3	0.08	2-nitrophenol	816	1.3
Se	1.3	0.005	2,4-dinitrophenol	316	ND
Ag	57.7	0.07	PCP	49	1.3
Cu	32.7	0.06	phenanthrene	21	1.4
Zn	3.1	0.005	anthracene	28	1.1

ND = Not detected (detection limit not defined).

The results show that xylenes were leached at a very high rate. IWT changed the formulation to HWT-21, and the new leachate concentration for xylenes dropped to 48 mg/L.

- The following extraction results were obtained by using solvents of various polarities. The higher the polarity index, the stronger the solvent.

	Solvent (polarity index)		
Contaminant	Dimethylsulfoxide (7.2)	n-Butanol (4.0)	Iso octane (0.1)
	Extractopm concentration, mg/L		
4-Methylphenol	10.0	5.5	1.9
Isophorone	2,179	1,213	695.3
2,4-Dimethylphenol	207.5	116	29.0
2-Nitrophenol	724	361	91.4
Hexachlorobenzene	0.15	0.10	0.24
PCP	21.3	13.7	5.6
Anthracene	3.3	4.7	22.8
Phenanthrene	6.5	3.9	19.2
Methylnaphthalene	0.22	0.12	0.84

The above table reveals that the greater the polarity of organic compound, the stronger the bonding to the matrix.

- Results for the infrared analyses, showing the frequency shifts for the various bonds studied, are presented below:

Compound	Treatment material frequency, 1/cm	Shift from untreated, 1/cm	Peak assignment
Nitrobenzene	1,150	-25	Aromatic mono substitution
	1,720	-22	C-N stretch
	2,929	- 5	C-H stretch
Phenol	934	-22	C-O stretch
	3,632	-8	H-bonded OH
Chloroaniline	662	22	C-Cl stretch
	2,348	6	C-H stretch
	3,542	-48	N-H stretch
Chloronaphthalene	660	19	C-Cl stretch
	2,611	-37	C-H stretch
Triethanolamine	2,297	193	Amine salt formation
	1,070	-5	H bonding

Some of the numerical results from the DSC tests were:

Compound	Literature value for heat of vaporization kcal/mole	Observed heat of vaporization kcal/mole	% Increase
Phenol	11.89	38.13	220.7
Trichloroethylene	8.32	34.43	314.2
Nitrobenzene	12.17	18.6	52.8
Triethanolamine	12.78	24.16	87.8

Additional observations of IWT are:

- All compounds leave the matrix at more than one temperature.
- Total energy involved in the treated matrix was much higher than the heat of vaporization of the pure compounds.
- When the effluent gases were analyzed, neither the original compound nor any of its fragments were seen.

Case Study D-6

Economic Analysis: Letter from Geo-Con, Inc., to Foster Wheeler Enviresponse, Inc., 8/30/88

Description

Geo-Con provided cost information for remediating the Hialeah, Fla., site using either a 1-auger or 4-auger machine. All costs provided include overhead and profit. The input is based on using 15 lb HWT-20 additive/100 lb dry soil.

Cost Component, $/yd^3	4-Auger	1-Auger
Labor	22.00	55.00
Equipment	28.00	70.00
Subcontracts	6.00	18.00
Other (purchases, insurance, health and safety)	9.00	25.00
Materials (HWT-20)	85.00	85.00
Mobilization/Demobilization, $		
Labor	26,000	9,000
Equipment	24,000	8,000
Subcontracts (trucking, etc.)	18,000	10,000
Other (purchases, insurance)	22,000	5,000
Subtotal	90,000	32,000
Capital Costs, $		
Augers	125,000	7,000
Flow control system	132,000	20,000
DSM drill	368,000	N/A
Leads	42,000	N/A
Power Pack	84,000	N/A
Subtotal	751,000	27,000

References for Appendices

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4. Technology Evaluation Report International Waste Technologies In Situ Stabilization/Solidification, USEPA ORD/RREL, Cincinnati, Ohio, 1989.

5. Prohibition on the Placement of Bulk Liquid Hazardous Waste in Landfills--Statutory Interpretive Guidance. EPA 530-SW-86/016, OSWER, Washington, D.C., 1986.